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THERMAL OXIDATION STABILITY OF DIESEL FUELS

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INTERIM REPORT
BFLRF No. 205

By

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Injector fouling bench tests (IFBT) and modified Jet Fuel Thermal Oxidation Test (JFTOT, ASTM D 3241) have been used to develop methodology for evaluating the thermal stability of diesel fuels. A new method for measuring the thickness of lacquer-type fuel deposits formed on test surfaces at elevated temperatures has been developed and applied to a variety of fuels, both with and without MIL-S-53021 (additive stabilizer package). The utility of this technique greatly expands the capability for exploring and defining diesel fuel thermal stability with respect to both material and kinetic studies. Correlation of IFBT and JFTOT type tests including definitions of temperature, flow, test surface metallurgy and fuel additive effects can now be performed to better understand diesel thermal stability and provide test methodology/test limit information for fuel specification consideration.

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FOREWORD

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The title on the DD Form 1473 is correct.
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Mr. Ed Frame (Belvoir F&L Research Facility) is acknowledged for his early important contribution to the initiation of this project. While screening high-temperature adiabatic lubricant candidates in late 1981 using a modified CLR-diesel (CLR-D) engine, Mr. Frame noted that occasional injector fouling occurred and suggested that the CLR-D hot test engine might be useful as a possible screening test for evaluating diesel fuel thermal stability. Mr. Frame's suggestion led to the successful funding of this project in 1982.

The senior technical assistance of Ms. Lona Bundy in making laboratory measurements and summarizing data has been invaluable to the authors of this report. Her program scheduling ability will be important to continued activity in defining diesel fuel thermal stability.

Ms. Janet Buckingham's (Southwest Research Institute) skillful use of statistical analytical computer software provided many of the more important calculations and graphs used in this report.

Dr. George H. Lee, II is acknowledged for his deligence in evaluating and modifying the Hot Liquid Process Simulator with the help of Mr. George Wilson (Alcor, Inc.) to perform JFTOT (ASTM D 3241) type tests.

Based on Mr. Jim Barbee's prototype deposit thickness measuring technique utilizing dielectric strength breakdown voltage, the successful design and fabrication of the Thermal Stability Deposit Measuring Device by Messrs. Doug Michalsky and James Luchemeyer is hereby gratefully acknowledged.

In addition, the Belvoir F&L Research Facility editorial staff is gratefully acknowledged for their patience and fortitude in assembling and preparing the text and data contained in this report. Thank you for your conscientious support.

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I. INTRODUCTION AND BACKGROUND

Compression ignition engine fuel injectors demand a certain degree of fuel thermal oxidative stability to maintain proper operation and expected spray quality. This stability requirement becomes more demanding as the injector is operated at higher temperatures. Compared to conventional compression ignition (CI) engine operation with the fuel being delivered at approximately 149°C (300°F), adiabatic engine operation can deliver the fuel at 260°C (500°F). Hypergolic CI engine combustion systems now in theoretical design stages will deliver fuel at 427° to 538°C (800° to 1000°F). The ability of a fuel to resist formation of deposits on internal injector system surfaces is a form of thermal oxidative stability which may be related indirectly to fuel storage stability.

Historically, injector fouling tests developed to correlate with fuel instability have not been very successful. At a symposium in 1958 (later reported in STP 244) (1)*, MacDonald and Jones reported on an injector test stating that:

> "Test fuel is passed through motor-operated, GM series 71 unit injectors at fuel flow rate of 1.6 mL per minute at a spray tip temperature of 204°C (400°F). Test cycle consists of 20 hours on test, rack injectors hot, return rack to off position, secure 4 hours, and rack cold prior to starting next 20-hour cycle. Continue cycles until injector sticks. Comments--at 400°F some fuels will cause sticking in less than 20 hours. Lowering spray tip temperature to 93°C (200°F) rates these fuels satisfactory. No fuel tested to date has caused sticking at this lower temperature, which is believed to be indicative of actual engine operating temperature. One fuel which caused injector sticking at less than 20 hours at 400°F was run successfully for 1000 hours in an operating engine (Bosch-type injectors). Reproducibility was poor and did not correlate with indicated stability of barge samples."

Meanwhile, work was ongoing at the U.S. Army's Coating and Chemical Laboratory (which was reported in February 1973) looking at thermal oxidative stability of

*Underscored numbers in parentheses refer to references at the end of this report.

automotive diesel fuels.(2) Fuel-oriented problems occurring in the field prompted this investigation. Because of the absence of any laboratory bench-scale techniques designed to predict these fuel filter plugging and/or injector fouling tendencies, initial experimentation was directed towards developing an accelerated thermal-oxidation technique. To establish valid test conditions, actual diesel fuel system temperatures were obtained from Engineering and Services (E&S) test programs and also monitored under road dynamometer testing. A second attempt involved the use of an ASTM-CRC Fuel Coker which was operated in a recycle mode to simulate the geometry of automotive diesel fuel systems. Initial experiments with this technique revealed its capability to differentiate diesel fuel quality in terms of thermal-oxidative stability. Since it was evident from the first study that fuel temperature profiles were changing the quality of diesel fuel under relatively short times of operation, a program was initiated with the Materials Test Directorate (MTD) to develop a laboratory capability for evaluating this fuel characteristic.(3) To accomplish this task, a laboratory rig was utilized to more closely simulate those environmental conditions prevailing in diesel fuel injector systems. A commercial fuel injector pump calibrating stand (Model SP8100D) located within the MTD facility was modified to permit the use of GMC 53 unit injectors. To provide differentiation between satisfactory and unsatisfactory fuels, the injector test stand was further modified as follows:

1) Heaters with adjustable temperature controls (above 93°C (200°F)) were installed in the fuel sump and return fuel line.
2) Fuel sump capacity was increased to at least 20 gallons and a variable speed drive installed.
3) A diverter valve was installed on the injector effluent line.

In order to differentiate fuel quality, the fuel injector pump calibrating stand was instrumented to monitor the following fuel temperatures:

1) Fuel in sump
2) Fuel to filter
3) Fuel to injector
4) Fuel from injector
5) Fuel to return sump.

Pressure differential across the test fuel filter was measured to define occurrences of filter plugging. Also, the injector fuel flow rate was measured to determine any change in output due to injector fouling. The injector stand was operated at 2200 rpm to simulate full load engine operation, and the fuel temperature to the filter was maintained at 107° to 116°C (225° to 240°F). To determine if this technique could in fact differentiate between fuels possessing different thermal-oxidation stability, three different fuels were subsequently evaluated. The first was a diesel fuel conforming to VV-F-800a grade DF-2, which was obtained from the MTD main fuel dispensing tank and was used for test equipment setup and preliminary testing. The other two samples were fuels that had exhibited fuel filter-plugging or some degree of injector seizure/fouling tendency. More specifically, one sample of DF-2 had been obtained from Camp Pendleton, a U.S. Marine Corps facility, where injector sticking problems had occurred during field maneuvers.(4) The other sample, also a DF-2, was obtained from a U.S. Air Force Strategic Air Command Minuteman installation in which excessive filter plugging had occurred during their normal emergency power generation operating procedure.(5) In subsequent evaluations of the two latter fuels in this modified injector stand, there was no manifestation of fuel filter plugging nor injector fouling. However, chemical analyses of the fuel samples before and after the individual tests revealed significant increases in existent gum proportional to the duration of the test.

In recent reviews of accelerated stability techniques for diesel fuels (6,7), the authors have implied that steam jet gum may be related to injector deposit/fouling and combustion chamber deposits; but in a review of diesel fuel deterioration and related problems in 1977 (8) and later at a 1980 Symposium (9), most Army diesel fuel system problems were reported as being found to be plugged primary fuel filters. This has led to a major activity in preventing diesel fuel stability-related problems. Recent incidences of fouled injectors have led to recognition of the need to inspect injector equipment being returned to rebuild facilities to identify if injector fouling (and subsequent inefficient fuel combustion) is occurring and to what degree.

In late 1981 and early 1982, while screening high-temperature adiabatic lubricant candidates in a modified CLR-diesel (CLR-D) engine, personnel at Belvoir Fuels and Lubricants Research Facility (BFLRF) at Southwest Research Institute (SwRI)

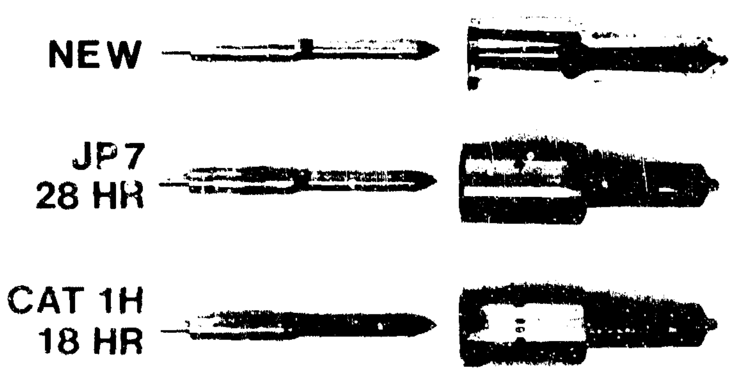
occasionally observed fuel injector fouling. The modified CLR-D was operated uncooled in the cylinder liner area with 149°C (300°F) coolant temperature in the head. Fouling of the Bosch APE 113 fuel injector occurred as plugged injector holes which resulted in erratic engine operation. A brief investigation was conducted to determine if the injector fouling was related to fuel properties. The results are shown in Table 1 (with a picture insert) as injector hole plugging at test hours, and a deposit demerit rating for the injector pintle shaft and tip. Jet Fuel Thermal Oxidation Tester (JFTOT) rating and steam jet gum fuel characterization properties are also shown for some of the test fuels in Table 1. Fuel A (JP-7) was evaluated because of its excellent JFTOT (ASTM D 3241) and gum (ASTM D 381) properties. When using Fuel A, no injector hole plugging was observed at 28 hours when the test was terminated. The injector pintle shaft and tip were inspected and found to be relatively clean. Next a fuel (B) suspected to have worse injector fouling performance, because of its higher gum content and JFTOT rating, was tested. Injector hole plugging occurred at 18 hours with increased pintle shaft and tip deposits. Then a new batch of the regular test fuel (C) used in the high-temperature CLR-D engine was evaluated. No hole plugging was observed at 63 hours when the test was terminated. Previously, fuel for the CLR-D test was supplied from a 55-gallon drum exposed to ambient summer temperatures, 38°C (100°F), and refilled only when empty. Thus, fuel for several tests was aged in the drum. As shown in Table 1, as Fuel C aged, the hours of operation until injector fouling was observed decreased. A new batch of unaged Fuel C was tested, and injector fouling did not occur even after 92 hours. The results of the screening were encouraging for developing a methodology of determining injector fouling tendencies of diesel fuels based on storage stability data. A program was initiated in September 1982 to develop a bench test for injector fouling evaluations of diesel fuel.

This report summarizes 3 years of effort in developing methodology to evaluate thermal oxidative stability of diesel fuels.

TABLE 1. HIGH-TEMPERATURE CLR-DIESEL BOSCH INJECTOR FOULING

Fuel	Results Injector Hole Plugging @ Test Hr	Injector Pintle Deposit Demerit* Shaft	Tip	JFTOT Rating**	Steam Jet Gum, mg/100 mL
A (JP-7)	None @ 28 hr	2.8	4.6	6	0.2
B (Cat 1-H)	One @ 18 hr	5.7	8.1	16	6.1
C (AL-11372 New)	None @ 63 hr	6.2	6.8	17	3.7
C (AL-11372 Aged)	Two @ 58 hr	5.0	8.2	ND***	ND
C (AL-11372 Aged+)	Two @ 27 hr	5.0	7.6	ND	ND
C (AL-11645 New)	None @ 92 hr	4.8	6.5	ND	ND

* 0 = Clean.
** Maximum TDR spun rating.
*** ND = Not determined.



II. OVERVIEW OF REPORT SECTIONS AND TEST FUELS

This report is composed of three major sections:

- Injector Bench Test Development
- D 3241 JFTOT Application to Diesel Fuel
- Application of Hot Liquid Process Simulator Instrumentation to Diesel Fuel Thermal Stability

While work in all these sections occurred during the performance period covered by this report, test fuel samples were not necessarily identical in each section. The following generic-type test fuels were made available in general to the program.

- **Cat 1-H:** Caterpillar 1-H/1-G engine reference fuel procured from Howell Hydrocarbons in San Antonio, TX, is a straight-run diesel fuel made in batches over the past 20 years
- **1%S:** One-percent sulfur referee diesel fuel meeting Specification MIL-F-46162B (all natural sulfur compound)
- **DFM:** Diesel fuel marine meeting Specification MIL-F-16884G
- **Navy Base Test Fuel No. 1:** Special test fuel procured under Specification MIL-F-16884H
- **JP-7:** Jet fuel procured under Specification MIL-T-38219A
- **EDS:** Experimental coal-derived fuel
- **Shale Oil Diesel:** Experimental shale oil-derived diesel fuel
- **Jet A-1:** Experimental test fuel procured under ASTM D 1655, "Specification for Aviation Turbine Fuels"
- **Diesel Control:** EPA specification for automotive emissions test fuel procured from Phillips Petroleum Company, Bartlesville, OK

III. INJECTOR BENCH TEST DEVELOPMENT

In late 1982, a project was initiated to develop an injector fouling bench test (IFBT). In order to determine the operating conditions required for the fuel injector fouling bench test rig, an initial attempt was made to determine the operating temperatures of the fuel injector nozzle in the uncooled CLR-D engine. By attaching thermocouples on the injector nozzle body and tip, it was felt the operating temperatures of the injector needle could be estimated.

A groove was ground along the injector body and nozzle to route the thermocouple wires out of the injector and the head of the engine. One thermocouple was spot-welded on the body of the injector nozzle above the seating surface, while the other was spot-welded to the injector tip below the seating surface (Figure 1). A washer was machined to fit over the tip and against the injector nozzle body to provide a seating surface for the nozzle. The grooves on the tip and nozzle body in the seating area were filled with a metallic epoxy to provide a seal and to protect the thermocouple wires (Figure 2).

The engine was started and warmed up to the operating conditions noted during previous tests when injector fouling occurred. The engine ran 90 minutes before the injector needle stuck open. The operating conditions of the engine prior to the injector failure are shown in Table 2. The failure of the injector is believed to

TABLE 2. CLR-D ENGINE OPERATING PARAMETERS

RPM	2000
Load, lb/ft	13.0
Air/Fuel Ratio	31:1
Coolant Temp, in Head, °C (°F)	152 (305)
Oil Temp, (sump), °C (°F)	132 (270)
Liner Temp, °C (°F)	
Avg	355 (672)
Min	319 (607)
Max	376 (708)
Exhaust Temp, °C (°F)	504 (940)
Injector Temp, °C (°F)	
Nozzle Body	218 (425)
Nozzle Tip	443 (830)

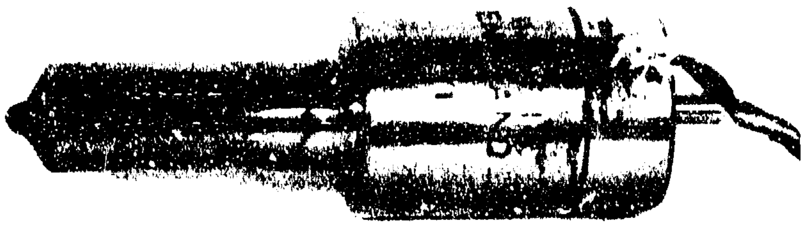


FIGURE 1. CLR INJECTOR NOZZLE WITH THERMOCOUPLE

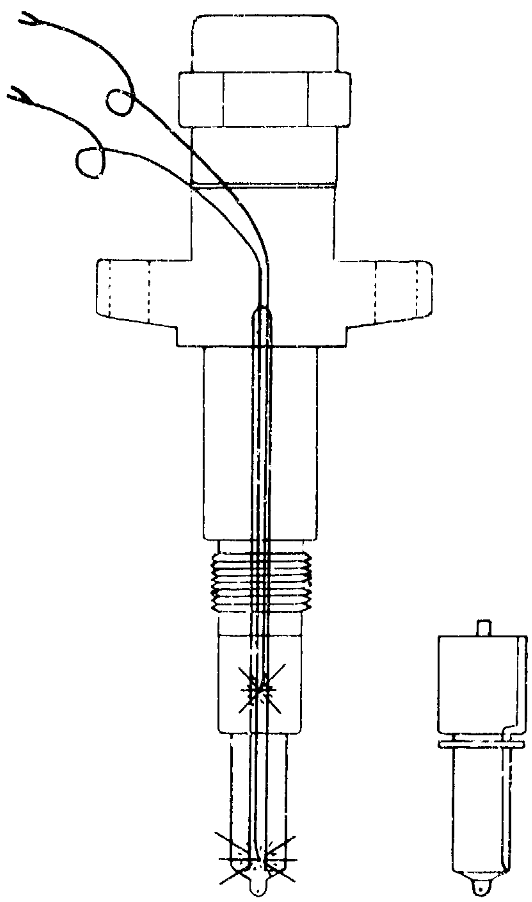


FIGURE 2. DETAILS OF CLR INJECTOR INCLUDING THERMOCOUPLES

have been caused by the uneven expansion of the injector nozzle due to metal removed to attach the thermocouple wires. An examination of the nozzle reveals scoring on the lapped surfaces of the needle, which seems to indicate that distortion did occur (Figure 3).

The temperature of the injector nozzle body, 218°C, was in the range of temperatures expected due to the thermal mass surrounding the injector in that area and its proximity to the head coolant. The temperature of the injector tip, however, was higher than expected. The temperature of the tip, 443°, was closer to the exhaust temperature (504°C) than the liner temperature (355°C), which indicates the thermocouple could have been exposed to flames from the combustion event.

To determine the operating temperature of the injector needle in the uncooled CLR-D engine, a 1.6-mm diameter templug was installed in a hole drilled 9.5 mm up from the injector needle tip (Figure 4). The templug was exposed to the steady-state operating temperature of the CLR-D engine for 2 hours. Upon analysis of the templug, the maximum temperature was determined to be 166°C (331°F).

Initial injector rig tests were performed with 2 gallons of Cat 1-H fuel, in which the injector effluent was recycled through the injector and pump, fouling the injector after 16 hours. The fouling occurred due to deposits building up on the needle tip, which caused the needle to stick and make the injector dribble. This method was determined to be unrealistically severe because the injected fuel is never recycled in an operating engine.

A test run using the injector bench test rig, with a one-pass fuel system, Figure 5, was run at conditions which attempted to simulate the uncooled CLR-D engine as shown in Table 3. The test was originally intended to continue until injector fouling or hole plugging occurred, with the injector needle deposition being rated at the beginning of each test day. The deposits on the injector needle were rated for two areas, the needle tip and the needle shaft (Figure 6). The method for rating the injector needle utilizes the CRC brown lacquer demerit scale normally used for rating engine deposits. The test was terminated at 56 hours, even though injector

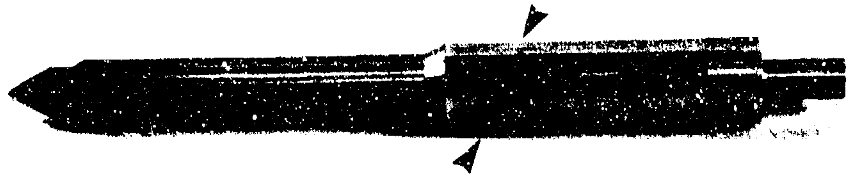


FIGURE 3. CLR INJECTOR NEEDLE (ARROWS INDICATE SCORED SURFACE)

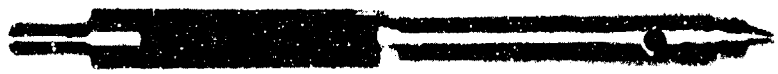


FIGURE 4. INJECTOR NEEDLE SHOWING POSITION OF TEMPLUG

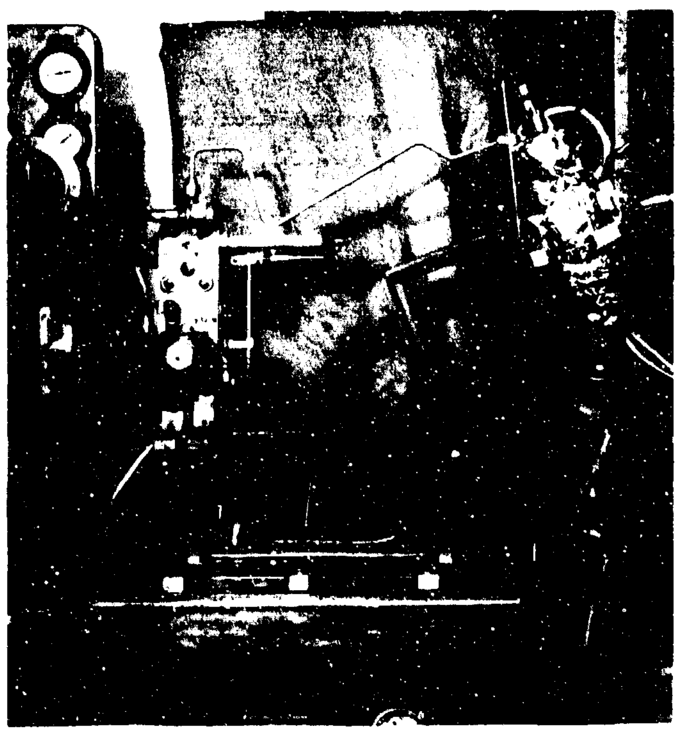


FIGURE 5. INJECTOR FOULING BENCH TEST RIG

TABLE 3. INJECTOR FOULING BENCH TEST OPERATING CONDITIONS

Injector Pump Speed, RPM	1000
Fuel Flow, lb/hr	3
Temperature of Nozzle Body Heating Block, °C (°F)	154 (310)
Temperature of Nozzle Tip Heating Block, °C (°F)	404 (760)

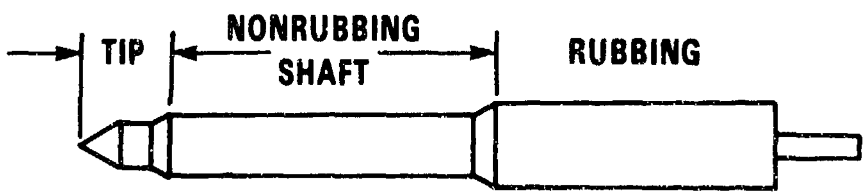


FIGURE 6. AREAS OF INJECTOR NEEDLE RATED FOR DEPOSITS

fouling or hole plugging had not occurred. The injector needle deposits had remained fairly constant (see Figures 7 and 8) after hour 14 of the test. Hence, the test was discontinued.

Since the amount of needle deposition, a tip demerit of 7.10 and a shaft demerit of 2.50, was considered inadequate for the time period in which the test occurred, the operating regime of the apparatus was examined. The operating temperature of the nozzle tip heating block was lower compared to the value of 435°C (815°F) measured previously on the nozzle tip in the operating engine.

Examination of the injector needle from the CLR-D engine which had operated 42 hours revealed a tip demerit of 6.15 and a shaft demerit of 3.00 using the same fuel (Cat 1-H fuel, AL-11804-F). Samples of both the fresh fuel and the fuel that had been through the injector test rig were analyzed by several laboratory methods to assess the differences in the two fuels. The results of these analyses are given in Table 4. Note that the fresh fuel is very unstable as measured by D 2274, but is

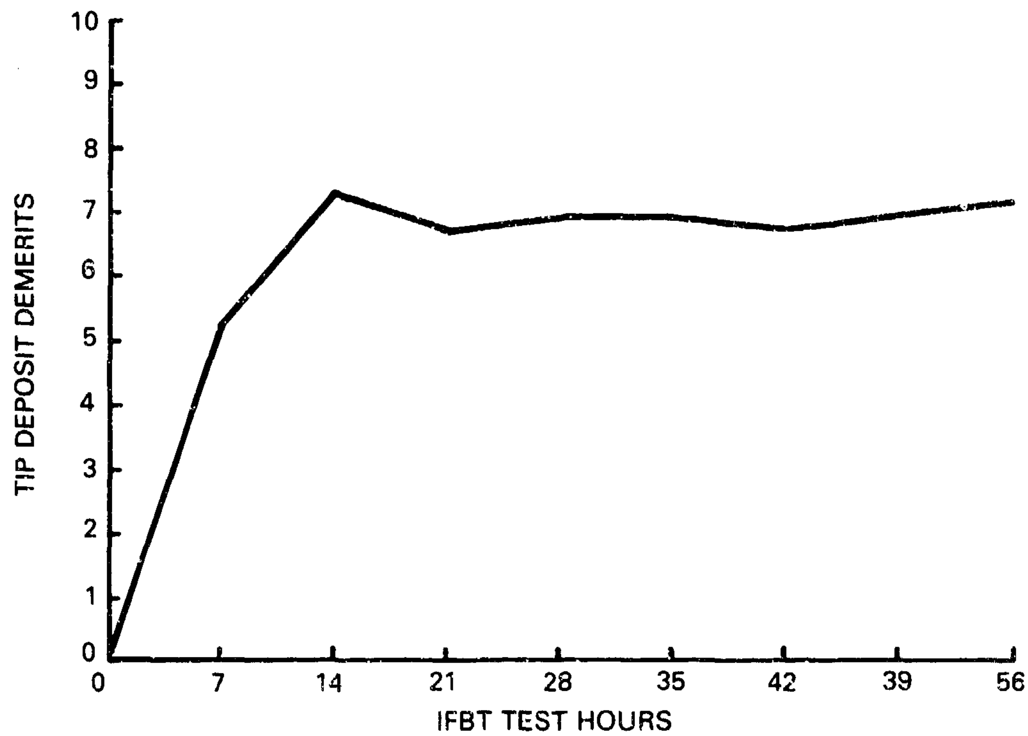


FIGURE 7. INJECTOR NEEDLE TIP DEPOSIT HISTORY

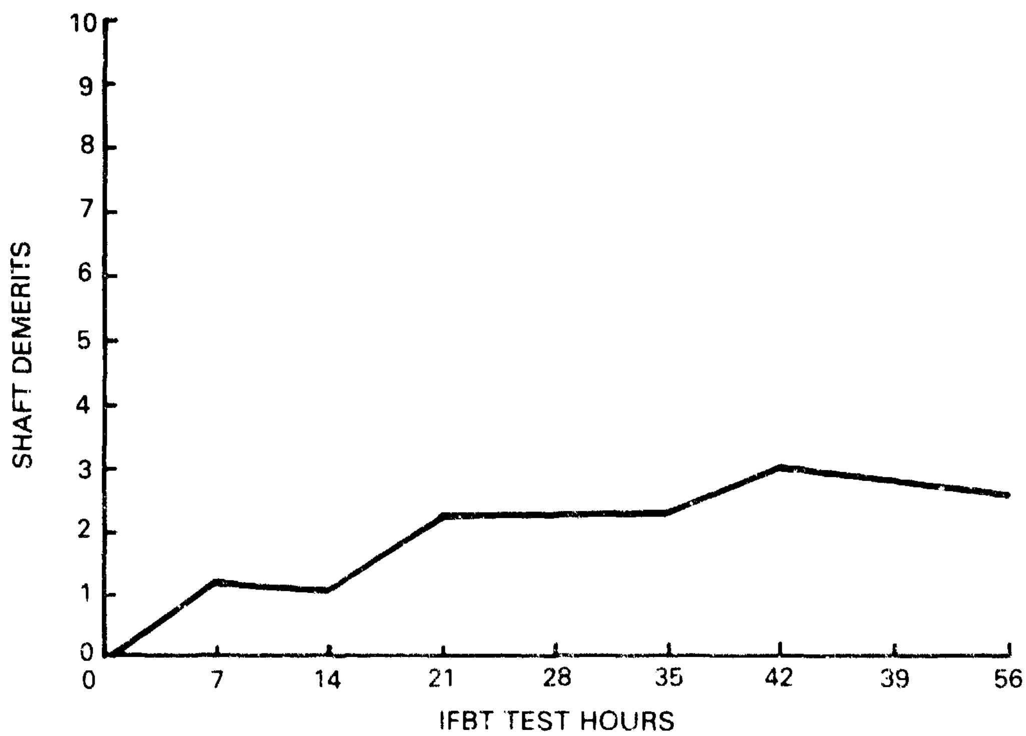


FIGURE 8. INJECTOR NEEDLE SHAFT DEPOSIT HISTORY

TABLE 4. RESULTS OF ANALYSIS OF FUEL IN THE INJECTOR FOULING BENCH TEST

Test	Fresh Fuel	Injector Spray Condensate
Accelerated Stability, D 2274, Total Insolubles, mg/100 mL	7.96, 8.06	3.82, 4.20
Particulates, D 2276, 0.8 µm, mg/L	3.6	35.2*
Steam Jet Gum, D 381, mg/100 mL	4.5	19.1**
Accelerated Stability, 150°C, 1.5 hr, mg/100 mL		
Filterable Insolubles	0.2	0.4
Adherent Insolubles	0.3	0.3
Soluble Gum	7.2	7.7
Thermal Oxidation Stability Test, JFTOT, D 3241, Maximum Spun Deposit Rating	10 @ 26	17 @ 38

* Sample plugged filter after 250 mL.
** Sample did not dry after 1 hour in block.

low in particulates. The injector spray condensate gives a lower D 2274 test result than the fresh fuel but is higher in particulates.

The similarity of bench and engine injector needle deposit ratings was encouraging because it was expected that the needle from the engine would have much heavier deposits, especially on the injector needle tip. Additional heaters were added to the injector tip heating block in order to raise the temperature further into the temperature regime of the engine. A short 15-hour test with a nozzle tip temperature of 474°C (885°F) gave demerits of 6.60 and 2.90 for the tip and shaft, respectively. Even though the deposition rate was too high, the trial indicated that the ability to control the rate of deposition on the needle was dependent on the nozzle tip temperature and was within the capabilities of the injector bench test apparatus. Another modification of the rig included a change in the geometry of

the injector mounts. A 56-hour test was operated with the injector mounted vertically. This position has since been changed to an angle of 20 degrees, which is the same as in the engine. It was felt the orientation of the injector could affect the sac volume of the injector tip, thus influencing deposit formation and hole plugging.

A templug was placed in the needle of the injector on both the CLR-D engine and the bench test. Both were warmed to their prescribed operating temperatures, and then operated for 6 hours to expose the templug. For the bench test apparatus, the nozzle tip heating block was operated at a temperature of 458°C (856°F), which produced a temperature of 209°C (409°F) at the injector needle. The temperature of the needle in the uncooled CLR-D engine was evaluated at 160°C (320°F), which corresponds closely to the 166°C (331°F) temperature measured in an earlier test. The temperature deviation between the engine and bench rig most likely accounts for any differences in the injector needle deposition noted during the side-by-side testing.

A side-by-side test was initiated which used the same fuel (Cat 1-H, AL-11804-F) with equal test durations and rating periods. The bench test apparatus had a nozzle tip heating block temperature of 461°C (861°F) for the duration of the 41-hour test. The injector needle deposition ratings are shown in Table 5 for the intermediate and final inspections for both the engine and bench test apparatus.

TABLE 5. INJECTOR NEEDLE DEPOSITION ENGINE/BENCH TEST COMPARISON (CAT 1-H FUEL)

	CLR-D Engine		Bench Test	
Hours	Tip Demerits	Shaft Demerits	Tip Demerits	Shaft Demerits
0	0	0	0	0
10	7.30	2.10	8.10	2.15
16	7.35	2.25	7.90	2.30
22	7.65	2.10	8.00	4.00
28	7.90	2.30	8.00	2.80
34	7.95	2.50	8.00	4.05
41	8.00	2.50	8.00	4.20

The results indicate a higher rate of deposition with the bench test apparatus and a tendency to develop a larger amount of injector needle shaft deposits. It is felt the deviations in the deposition rate are attributable to the temperature differences of the injector needles as noted earlier. Although deposits were formed, injector fouling or hole plugging had not occurred at anytime during the testing in either injector. For both injectors, the pop-off pressure remained the same, and the spray pattern looked good.

The bench test rig was then operated using test fuel (AL-11804) which had been aged for both 1 and 2 weeks at 80°C. Samples of the fuel from both aging periods were analyzed by several laboratory methods. The results of these analyses are given in Table 6. Note that the aged fuel continues to be unstable as measured by

TABLE 6. RESULTS OF THE ANALYSIS OF FUELS IN THE INJECTOR FOULING BENCH TEST

Test	Fresh Fuel	Test Fuel AL-11804-F Aged at 80°C: One Week	Test Fuel AL-11804-F Aged at 80°C: Two Weeks
Accelerated Stability, D 2274, Total Insolubles, mg/100 mL	8.0	7.5	3.9
Particulates, D 2276, 0.8 μm mg/L	3.6	3.3	18.5
Steam Jet Gum, D 381, mg/100 mL	4.5	22.7	26.0
Accelerated Stability, 150°C, 1.5 hr, mg/100 mL			
Filterable Insolubles	0.2	3.1	10.1
Adherent Insolubles	0.3	0.4	0.4
Soluble Gum	7.2	17.6	38.9
Thermal Oxidation Stability, JFTOT, D 3241			
• 260°C*			
Pressure Differential, mm Hg	110 at 150 min	0	0
Preheater Deposit Code	4	3	>4
TDR Spun Deposit Rating	20 at 40	12 at 40	>50 at 35
• Breakpoint Temperature, °C	221	255	190

* Test Temperature.

ASTM D 2274. The aged fuels show a significant increase in particulates and steam jet gum as compared to the fresh fuel. The dramatic increase in the 150°C test results for the 1-week and 2-week aged samples may be significant.

A test was initiated with the fuel that was aged 1 week (in an attempt to promote injector fouling) in the bench test and the engine. Since the injector needle deposition did not appear to be sufficient to cause injector fouling, the test was terminated after 24 hours. The intermediate and final deposit ratings are shown in Table 7 for both the engine and bench test apparatus. The data indicate the bench

TABLE 7. INJECTOR NEEDLE DEPOSITION ENGINE/BENCH TEST COMPARISON (CAT 1-H FUEL AGED FOR 1 WEEK AT 80°C)

	CLR-D Engine		Bench Test	
Hours	Tip Demerits	Shaft Demerits	Tip Demerits	Shaft Demerits
5	4.60	1.15	6.40	1.30
11	4.90	1.30	6.05	2.40
17	7.30	1.65	6.65	1.90
24	6.50	1.20	5.20	1.95

test is somewhat more severe with a higher rate of deposition, especially in the shaft area of the injector needle. For this bench test, the injector nozzle tip heating block was operated at a temperature of 437°C (819°F). An interesting occurrence is the apparent "self-cleaning" of the injector needle during the last rating period. The continuation of this trend is doubtful. It is speculated from previous data that the deposit rating would again increase. During this test, in both the engine and injector apparatus, the rater noted the pintle motion to be sticky in the injector; however, the pop-off pressure and spray pattern looked good for the duration of the test.

The Cat 1-H test fuel (aged for 2 weeks at 80°C) was then run in the CLR-D engine and the injector bench test rig. During this test, injector fouling occurred in both the engine and bench rig after 13 hours of operation. The injector in the engine fouled due to hole plugging. The injector in the rig fouled when the needle stuck open, causing the injector to dribble at a low opening pressure. The

intermediate and final deposit rating demerits are shown in Table 8 for both apparatus. The data show the injector rig to be more severe, but also seem to

TABLE 8. INJECTOR NEEDLE DEPOSITION ENGINE/BENCH TEST COMPARISON (CAT 1-H FUEL AGED FOR 2 WEEKS AT 80°C)

	CLR-D Engine		Bench Test	
Hours	Tip Demerits	Shaft Demerits	Tip Demerits	Shaft Demerits
7	7.20	0.40	8.00	1.15
13	2.85	0.60	8.85	1.90

indicate a different mode of fouling. The deposits in the engine seemed to have built up, then through a "self-cleaning" action, caused the hole plugging to occur. A theory is that the deposits accumulate, then are washed off by the fuel pressure and flow; and, if the deposits are present in sufficient quantities, the injector holes will plug. The bench test apparatus seems to develop a harder type of deposit, which then accumulates to the point at which it inhibits the injector needle motion. This appears to be substantiated by the higher deposition ratings for the bench rig. An examination of the needle shaft revealed deposits on the lapped surfaces, along with the heavy deposits on the tip and seating surfaces. The injector nozzle tip heating block was operated at a temperature of 439°C (822°F) for this test. It appears the bench test apparatus is being operated at a higher temperature than the CLR-D engine; however, it was encouraging that injector fouling could be obtained in a parallel run with the engine.

Comparative photographs were taken of the spray from a new injector nozzle, the fouled bench test nozzle, and the fouled CLR-D nozzle. The photographs were taken using a diffused laser strobe front lighting the injector tip, which was triggered by the needle lift of the injector. The photographs shown in Figures 9 through 11 were taken at 0.6 ms after the start of needle lift. Figure 9 is a photograph of a new injector nozzle. Note the well-developed spray, particularly the cone angle and the penetration from each of the four holes. Figure 10 shows the nozzle from the injector fouling bench test apparatus. The mode of fouling with this nozzle was a needle stuck due to a buildup of deposits. Initial attempts to photograph the nozzle failed because of insufficient needle lift to trigger the laser

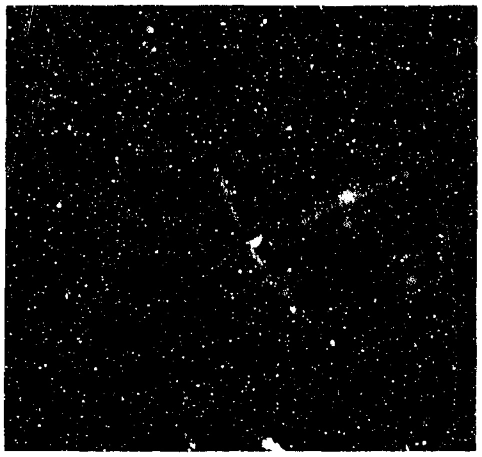


FIGURE 9. NEW INJECTOR NOZZLE

FIGURE 10. FOULED NOZZLE FROM INJECTOR FOULING BENCH TEST APPARATUS

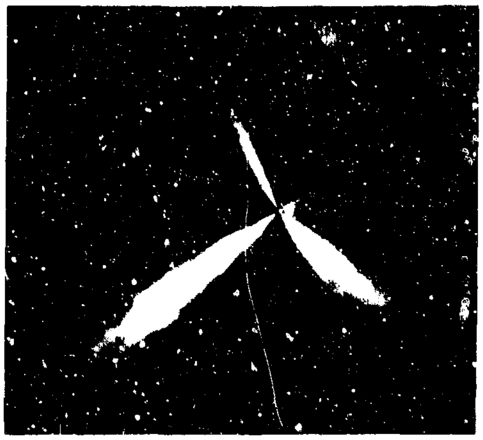


FIGURE 11. FOULED INJECTOR NOZZLE FROM CLR-D ENGINE

and camera. The needle and nozzle body were separated, soaked in diesel fuel, then reassembled for the picture. It is apparent from the photograph that the cone angle of the spray is narrower than with the new nozzle, along with a greater penetration of the spray. The narrow cone angle of the spray is probably due to the pintle sticking and partial hole plugging. In an engine, a nozzle with these characteristics would have poor atomization of the fuel because of the narrow cone angle, along with fuel impingement on the piston crown and the cylinder walls because of the deeper penetration. Figure 11 is a photograph of the injector nozzle from the CLR-D engine. It is apparent that there is one hole almost completely plugged, and the two neighboring holes appear to be partially plugged. One of the partially plugged holes shows evidence of two plumes emitting from the same hole. The other apparently partially plugged hole shows a spray with a narrower cone angle and deeper penetration than the new nozzle. The comparative photographs seem to indicate that there is some correlation between the IFBT apparatus and the CLR-D engine in the fouling of injector nozzle holes. That both fouled nozzles exhibited sprays with narrow cone angles was encouraging in the development of the IFBT procedures. A further refinement

in the operating temperatures of the IFBT apparatus would lead to a more direct correlation with the CLR-D engine.

Tests were performed to determine the role of lubricants in injector tip fouling. The impetus for examining the lubricant role spawned from a routine daily fouling of injector nozzles in the CLR-D engine during a lubricant evaluation. The fuel used during the testing was a sample of Cat 1-H fuel which previously did not display any injector tip fouling in the engine or IFBT rig. A noticeable increase in the consumption of the test lubricant indicated the lubricant as an important mechanism and/or source in the fouling of injector nozzles.

The IFBT apparatus was operated on the Cat 1-H fuel that was being used in the CLR-D engine test when the injector fouling problems occurred. There was no evidence of injector tip fouling when the test was terminated after 39 hours; the intermediate and final deposition ratings for the test are in Table 9. The rating

TABLE 9. INJECTOR NEEDLE DEPOSITION-BENCH TEST (CAT 1-H FUEL)

	Rating	
Hours	Tip Demerits	Shaft Demerits
7	6.80	2.20
14	7.15	2.60
20	8.50	2.60
27	8.50	2.60
32	8.50	2.60
39	8.00	2.60

results indicate that there was no increase in needle deposition when compared to an earlier 41-hour test run with the Cat 1-H fuel. This test was used to confirm that the lubricant was influential in causing the injector tip fouling in the uncooled CLR-D engine. It was proposed to use a very stable fuel such as JP-7 in the engine to determine if the injector fouling that had occurred was totally lubricant related or had some contribution from the fuel.

Previous tests in the CLR-D engine had shown no incidence of injector fouling with a JP-7 fuel. A test was run in the engine using JP-7 fuel and the lubricant that had caused the earlier fouling tendencies. The initial rating of the needle at 6 hours revealed heavy tip deposits below the seating surface in the sac volume area, while the shaft deposits were very light (Table 10). After 12 hours

TABLE 10. SUMMARY DATA USING JP-7 (AL-12124-F) IN BENCH TEST AND ENGINE TESTS

	Injector	Nonrubbing	Rubbing	Tip	Operation
IFBT No. 9	Bosch API				
June 1983	6 hr	2.40	--	6.10	OK
	12 hr	2.80	--	4.65	OK
	19 hr	2.35	--	6.70	OK
	25 hr	2.70	--	5.70	OK
	31 hr	3.50	--	7.00	OK
Engine	Bosch API				
(Poor Oil)	6 hr	1.80	--	8.10	Two holes plugged
May 1983	12 hr	3.45	--	7.30	Two holes plugged
Engine	Bosch API				
(Poor	7 hr	2.00	--	5.40	OK
Oil)	13 hr	3.80	--	5.70	OK
June 1983	19 hr	3.45	--	6.90	One hole plugged

of operation, two holes were plugged. An inspection of the nozzle revealed heavy carbon buildup around the two plugged holes, as shown in Figures 12 and 13. A new nozzle was installed in the engine. After 13 hours of operation, a buildup of carbon was observed on the very tip of the needle which protrudes into the sac volume, Figure 14. The inspection at hour 19 revealed one plugged hole and an absence of the carbon buildup on the tip noted earlier. It is believed the carbon flaked off and plugged the nozzle hole. Due to the carbon buildup on the nozzle and needle tip, the injector fouling in this experiment is believed to have been lubricant related. The JP-7 test fuel was operated in the IFBT apparatus for 31 hours (data summarized in Table 10). The deposit ratings, when compared to Cat 1-H fuel at approximately the same time, indicated no increase in injector needle deposition; the CLR-D engine operating on JP-7 fuel fouled two injectors at 12 and

FIGURE 12. PLUGGED HOLE SHOWING HEAVY CARBON BUILDUP

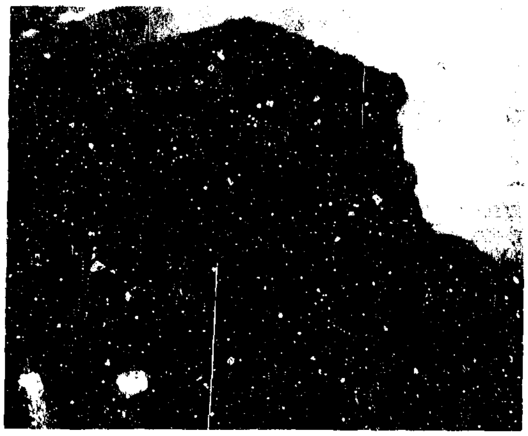


FIGURE 13. SECOND PLUGGED HOLE SHOWING HEAVY CARBON BUILDUP

FIGURE 14. NEEDLE TIP SHOWING CARBON BUILDUP

19 hours of operation (Appendix A). The IFBT data seem to confirm that the injectors fouling in the engine could be attributed to the engine lubricant.

In a research program conducted by the U.S. Army Tank Automotive Command (Warren, Michigan) on a hypergolic engine, the fuel was raised to 7000 psi and 649°C (1200°F) prior to injection. Deposits formed on the walls of the fuel line and plugged the lines, which resulted in less than 20 minutes of test time using a diesel fuel. As a result, a JP-7 fuel thought to be more thermally stable was obtained by BFLRF, and thermal oxidation stability tests (JFTOT) were conducted on the fuel (both neat and additive treated (MIL-S-53021)). The results of the test are presented in Table 11. No filter plugging occurred in any of the D 3241 runs, and the spun deposit rating showed essentially no difference between neat and additive-treated fuels. However, the particulate results for the effluent do show a difference between neat and additive-treated fuel. The additive may provide additional protection from fouling of fuel lines to the hypergolic injector. Even without the additive, the use of JP-7 test fuel would provide for longer test times compared to the current diesel test fuel.

TABLE 11. THERMAL OXIDATION STABILITY TEST (JFTOT) FOR FUEL AL-12124-F

D 3241, Test Temperature, °C (°F)	Maximum Spun Deposit Rating				Particulates in Effluent, D 2276, 1.2 μm, mg/L	
	Neat		With Additive*		Neat	With Additive*
	Visual Code	TDR Spun	Visual Code	TDR Spun		
218 (425)	>2	12 @ 35	1	7 @ 45	3.4	0.9
260 (500)	>3	6 @ 44	1	9 @ 48	2.9	0.9
343 (650)	4	38 @ 49	>4	44 @ 55	6.0	1.4
427 (800)	4	>50 @ 32	>4	>50 @ 41	3.7	1.3
471 (880)	>4	>50	>4	>50 @ 39	5.5	1.3

* MIL-S-53021 (without biocide)

A coal-derived fuel blend (55/45 vol% blend of Cat 1-H and EDS coal-derived fuel) was evaluated in the IFBT apparatus and operated for 41 hours without any injector nozzle fouling. The final deposition ratings (8.40 and 4.70 tip and shaft demerits, respectively) were only slightly higher than the Cat 1-H fuel tip (8.00) and shaft (4.20) demerits. However, the deposit buildup on the injector tip using the EDS blend appeared to be heavier and softer than the deposits from the Cat 1-H fuel. Additionally, a thin film of deposits which had not been seen before was noted on the shaft of the injector; however, this deposit did not impair the pintle motion as the pop-off pressure and spray remained good throughout the test.

Attempts were initiated to correlate injector pintle deposition with fuel JFTOT breakpoint temperature for both neat and aged Cat 1-H fuel and a 1-percent sulfur referee fuel. A JFTOT breakpoint temperature was determined for each fuel using standard JFTOT aluminum tubes. The IFBT apparatus was operated concurrently on the same fuel to determine the injector fouling tendencies of the fuel. In addition to the visual deposit rating of the injector pintle, a Tube Deposit Rater (TDR) spun deposit rating was performed to trace the deposition rate on the pintle. Mounting fixtures were made to allow ALCOR MARK 9 Tube Deposit Rater (for D 3241 test tubes) to accept and rate injector pintles.

The data for the three test fuels and IFBT test results are shown in Table 12. These were a Cat 1-H neat and aged 3 weeks and MIL-F-46162B referee grade diesel fuel containing 1 percent sulfur (with t-butyl disulfide added). The Cat 1-H results were interesting in that after aging at 80°C for 3 weeks, the fuel appeared to be more stable than the unaged fuel. This is in contrast to an earlier sample of Cat 1-H fuel aged 2 weeks which exhibited injector fouling at 13 hours and a relatively low JFTOT breakpoint (190°C).

TABLE 12. FUEL ANALYSIS

	Cat 1-H (before aging)	Cat 1-H (after aging), 3 weeks	AL-12329-F MIL-F-46162B Referee grade diesel fuel (1% sulfur)
ASTM D 2274, mg/100 mL	6.9	2.2	0.2
ASTM D 2276, mg/L	4.8	17.4	3.5
JFTOT Breakpoint, °C*	215	238	254
IFBT Test No.	11	12	13
IFBT Test Duration, hr	40	40	18
TDR Spun Deposit Rating (near tip at end of test)	ND**	31	47
CRC Rating: • Tip	3.0	7.1	6.3
• Shaft	1.95	3.45	3.6
100% Hole plugging	None	None	None
Spray Pattern	Good	Good	Dribble
Opening Pressure (at end of test), psi	2500	2500	1200

* - D 3241 visual deposit rating Code 3 inception temperature.
**ND - Not determined.

A second IFBT test (IFBT Test No. 14) was performed using the MIL-F-46162B referee grade diesel fuel containing 1-percent sulfur. As with the earlier test, the fuel fouled the injector in a period of 18 hours. The fouled injector dribbled fuel

at 100 psi and could not attain the pop-off pressure of 2500 psi. The fouling in the previous test was also due to poor sealing, with the dribble starting at a somewhat higher pressure of 1200 psi. The tip and shaft demerits for both tests (IFBT Test Nos. 13 and 14) with this fuel are shown in Table 13. It is felt that a buildup of deposits on the seating surfaces led to the fouling of the injector nozzles.

TABLE 13. IFBT TIP AND SHAFT DEMERITS FOR TWO RUNS OF MIL-F-46162B REFEREE GRADE DIESEL FUEL

IFBT Test 13			IFBT Test 14		
Hours	Tip Demerits	Shaft Demerits	Hours	Tip Demerits	Shaft Demerits
4	6.40	1.40	6	5.30	2.10
12	6.00	3.10	12	6.40	2.60
18	6.30	3.60	18	7.35	2.80

Two additional IFBT test rigs were fabricated utilizing DD 6V-53T (N70) and Cummins NH-220 injectors. Test procedures are provided in Appendix B. Injector bench tests (IFBT No. 15) were run using Cat 1-H fuel (AL-11804-F) (JFTOT Breakpoint Temperature of 216°C in Table 15) in the Bosch, Detroit Diesel, and Cummins injector rigs to determine deposition on the injector pintles. The rating areas were altered to examine both the rubbing and nonrubbing surfaces of the pintles and plunger. It was felt the nonrubbing surface deposits would be indicative of a fuel's thermal stability and provide a better correlation with JFTOT data. The rubbing surface deposits would be indicative of injector sticking, i.e., low injection pressures and poor spray patterns. The ratings and injector checks were examined at the end of the test period of 35 hours. It was felt that daily examination of the injector pintles and plungers could disrupt the formation of deposits. Because of the changes in the ratings, the ratings for this test can not be directly correlated with previous tests. However, the pop-off pressure and spray pattern with the Bosch injector indicated this test corresponded with previous tests with the same test fuel. The rating data for the three injection rigs are shown in Table 14, with the relative sizes and areas of the plungers shown in Figure 15. The Cummins plunger shows very little deposition, and this appears to be a function of its mode of operation, i.e., the PT fuel system. Talks with

TABLE 14. INJECTOR DEPOSIT RATING RESULTS

IFBT Test No.	Injector	Length of Test (Hr)	Surface Rating Demerits (0 = Clean)		
			Nonrubbing	Rubbing	Tip
15	Cat 1-H - (AL-11804-F)				
	Cummins NH-220	35.0	0.0	0.16	
	Bosch API	35.0	1.95	1.15	
	DD 6V-53T (N70)	35.0	3.70	2.50	
19	Cat 1-H - Aged 2 Weeks				
	Bosch API	39.0	5.40	2.25	6.95
	DD 6V-53T	38.0	0.95	0.20	4.15
17	Cat 1-H - Aged 4 Weeks				
	Cummins NH 220	43.0	N/A	0.80	0
	Bosch API	38.0	2.35	0.50	6.55
	DD 6V-53T	43.0	2.10	2.35	4.95
18	DFM (AL-8350-F)				
	Bosch API	36.0	4.70	3.10	7.40
	DD 6V-53T (N70)	43.0	4.25	4.00	4.95

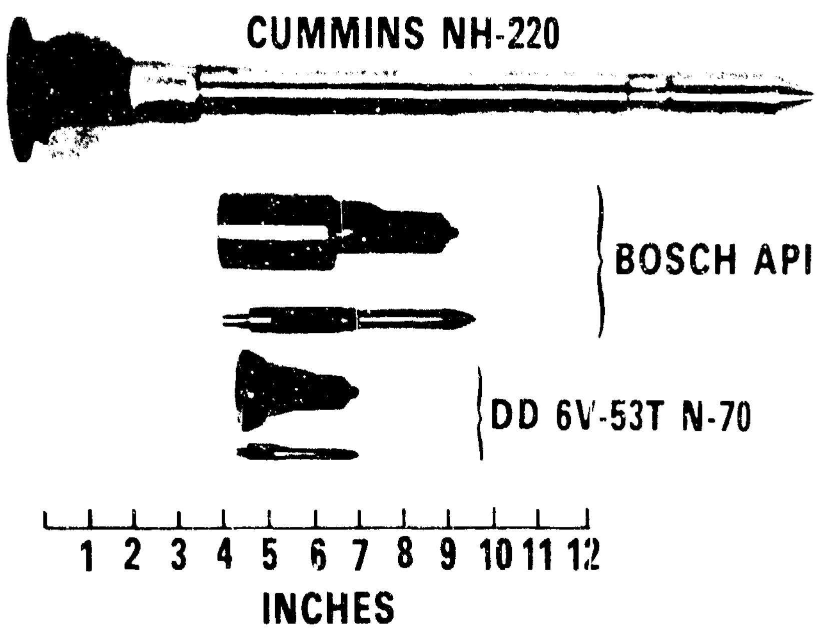


FIGURE 15. RELATIVE SIZES AND AREAS OF THE THREE INJECTION SYSTEMS EXAMINED

personnel of Cummins Engine Co. indicate injector coking occurs primarily at motoring conditions, in which the plunger compresses mostly air, and tip temperatures have been measured to be as high as 871°C (1600°F). With the PT system, fuel flow is never shut off. Even at motoring conditions, a small amount of fuel is used for cooling. The fuel, if thermally unstable, combined with cylinder gases (air, unscavenged exhaust, lubricant) blowing up into the nozzle, tip, can cause injector coking. The DD 6V-53T nozzle appears to be the most severe. The nozzle stresses the fuel by circulating it for cooling, which could account for the increased pintle deposition.

In addition to the injector deposit rating results for Cat 1-H in Table 14, data are also provided for Cat 1-H aged at 80°C for 2 and 4 weeks and a high-sulfur DFM. Accelerated stability test results for these four fuels are summarized in Table 15. The results of the 2-week aged Cat 1-H demerit ratings appear to have been influenced by nonconformal operating temperatures. The injector effluent temperatures were 23°C higher for the Bosch API rig and 29°C lower for the Detroit Diesel rig than the other test fuels.

The 4-week aged Cat 1-H fuel (AL-11804-F) was examined in each of the three injection rigs. The deposit rating on the Cummins plunger was similar to the other test fuels examined. The Detroit Diesel 6V-53T unit injector revealed deposit ratings similar to the unaged Cat 1-H test; however, the spray pattern was not fully developed. The Bosch API pintle also revealed ratings similar to the unaged Cat 1-H fuel.

The other test completed was with a high-sulfur DFM (AL-8350-F). The fuel was not examined in the Cummins injector, because the deposition mechanisms could not be duplicated with the Cummins bench test rig. Both the Bosch API and Detroit Diesel 6V-53 injector pintles revealed deposit ratings heavier than the base Cat 1-H fuel.

Injector fouling bench tests were run on a middle distillate fuel derived from shale (FL-410-F) using the Bosch API and the Detroit Diesel 6V-53 injector rigs. The deposit rating test results are shown in Table 16. The shale-derived fuel was obtained from the Department of Energy and had been prepared by Sun Tech, Inc. from a feedstock that was a partially hydrotreated Geokinetic crude shale oil

TABLE 15. ACCELERATED STABILITY TEST RESULTS

	Cat I-H (AL-11804-F)	Aged Cat I-H at 2 Weeks	Aged Cat I-H at 4 Weeks	DFM (AL-8350-F)
D 2274, mg/100 mL	5.6	6.4	4.4	5.1
150°C Test, mg/100 mL,				
1.5 hr				
Filterable Insolubles	3.9	3.5	5.3	9.4
Adherent Insolubles	0.6	0.8	1.1	1.4
Total Insolubles	4.5	4.3	6.4	10.8
3 hr				
Filterable Insolubles	5.2	8.3	9.4	17.3
Adherent Insolubles	0.9	1.7	1.3	1.2
Total Insolubles	6.1	10.0	10.7	18.5
D 2276, mg/L	3.0	4.4	11.0	25.4
JFTOT, D 3241,				
Temperature, °C (°F)	204 (400)	224 (435)	204 (408)	199 (390)
ΔP, mm Hg @ Time, min.	0 @ 150	125 @ 148	10 @ 150	0 @ 150
Visual Code	2	3	3	>2
TDR Spun Max.	5 @ 41	33 @ 24	9 @ 40	14 @ 42
Temperature, °C (°F)	216 (420)	232 (450)	207 (405)	204 (400)
ΔP, mm Hg @ Time, min.	0 @ 150	125 @ 18	125 @ 107	0
Visual Code	<3	3	>3	4
TDR Spun Max.	8 @ 40	23 @ 18	6 @ 42	21 @ 40
Temperature, °C (°F)	238 (460)	249 (480)	221 (430)	232 (450)
ΔP, mm Hg @ Time, min.	0 @ 150	125 @ 102	125 @ 86	69 @ 30
Visual Code	4	>4	>4	>4
TDR Spun Max.	17 @ 40	29 @ 17	22 @ 42	>50 @ 43
Breakpoint Temp., °C	216	230	204	201

TABLE 16. DEPOSIT RATING TEST RESULTS FOR SHALE-DERIVED DIESEL FUEL (FL-0410-F)

IFBT Test No.	Injector	Length of Test (Hr)	Surface Rating Demerits (0 = Clean)		
			Nonrubbing	Rubbing	Tip
Aug 1984					
20	Bosch API	42.0	1.45	1.40	6.95
	DD 6V-53T	46.0	2.40	1.50	5.40

recovered by in-situ retorting of Utah oil shale. No additive was used in the preparation of this fuel. Some of the more pertinent properties of this shale oil diesel fuel are listed in Table 17.

TABLE 17. PROPERTIES OF SHALE OIL DIESEL (FL-410-F)

Accelerated Stability	
D 2274, mg/100 mL	0.33
Filterable Insolubles, 150°C	
1.5 hr, mg/100 mL	29.61
3.0 hr, mg/100 mL	47.2
Adherent Insolubles, 150°C	
1.5 hr, mg/100 mL	2.2
3.0 hr, mg/100 mL	3.6
Steam Jet Gum	
1.5 hr, mg/100 mL	127.9
3.0 hr, mg/100 mL	150.7
D 86, Distillation, °C	
IBP	180
50%	251
90%	304
End Point	341
Gravity, °API	39.5
Cetane Number	51
Sulfur, wt%	0.04
Nitrogen, wt%	0.094
Carbon, wt%	86.0
Hydrogen, wt%	13.8
Oxygen, wt%	0.060
Hydrocarbon Type, vol%	
Saturates	81.0
Olefins	1.2
Aromatics	17.8
Existent Gum, mg/100 mL	4.8
Particulate Contamination	
D 2276, mg/L	99.2

Thermal oxidation tests (ASTM D 3241-77, JFTOT modified) to determine the breakpoint temperature were run on the shale-derived diesel fuel (FL-410-F) shown in Table 18, which gave a break point temperature of approximately 234°C.

TABLE 18. THERMAL OXIDATION TESTS TO DETERMINE BREAKPOINT

Fuel Type:	Shale-Derived Diesel Fuel	
Fuel Code:	FL-410-F	
Maximum Tube Temperature, °C (°F)	ASTM Visual Code	P, mm Hg/min
224 (435)	-	-
232 (450)	2	7.4/150
235 (455)	3*	8.6/150
241 (465)	>4	9.0/150
249 (480)	>4	8.3/150
260 (500)	>4	8.6/150

* Denotes approximate breakpoint.

Ten pintles from Bosch API injectors were examined by the MARK 9 TDR and by dielectric strength measurements. The pintles were from injectors that had been previously run in bench tests. The results obtained from three of the evaluations are illustrated for comparison. Fuels and conditions used during injector fouling bench tests of these three pintles were the following:

IFBT No. 19: Pintle (A) - Cat 1-H fuel fuel fuel aged 2 weeks at 80°C. Approximate JFTOT breakpoint 232°C.

IFBT No. 20: Pintle (B) - Shale-derived fuel containing ≈ 0.1 percent N. Approximate JFTOT breakpoint 235°C.

IFBT No. 18: Pintle (C) - A DFM fuel containing ≈ 1.2 percent S. Approximate JFTOT breakpoint 201°C.

Figure 16 is a photograph of a new pintle to aid in determining the physical locations of the pintle stations. Figures 17 through 22 are graphs of measurements obtained using MARK 9 TDR and dielectric strength breakdown voltage.

The MARK 9 TDR ratings for all three pintles are similar. This technique uses light absorbance to determine rating and does not discriminate between the varnish-like deposits and other deposits such as carbon streaks.

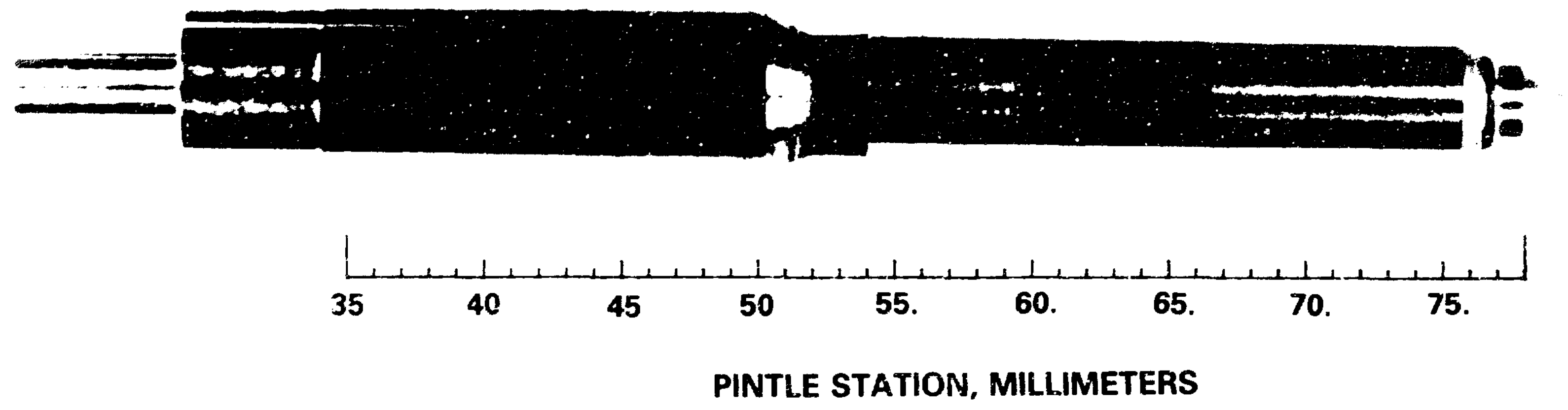


FIGURE 16. PINTLE SHOWING PINTLE STATIONS

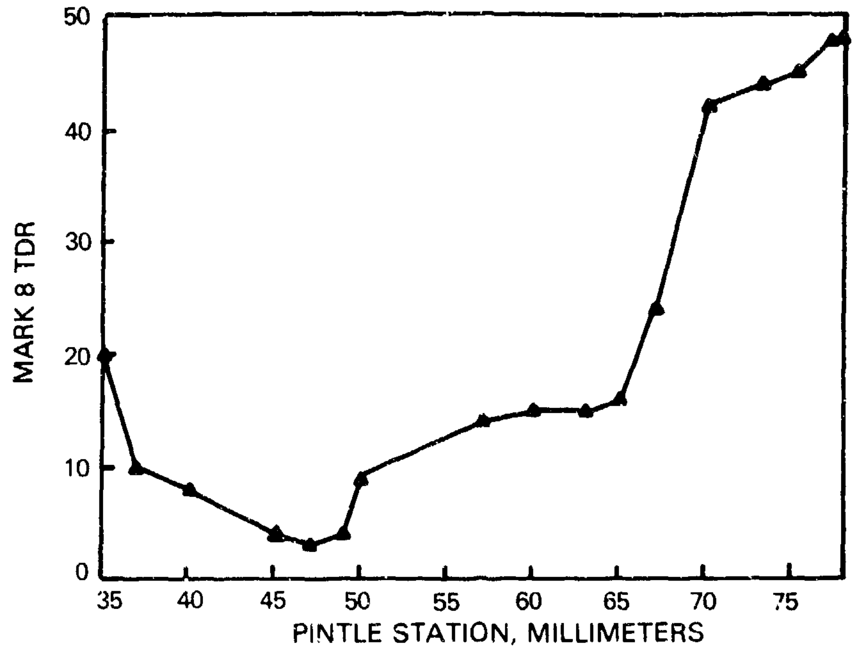


FIGURE 17. TDR RATING OF PINTLE A

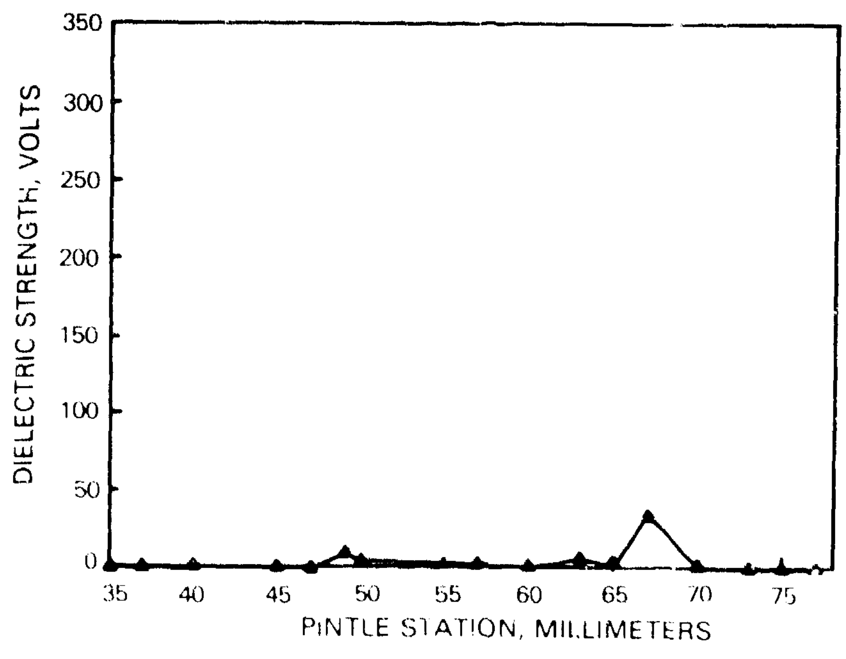


FIGURE 18. DIELECTRIC STRENGTH OF PINTLE A

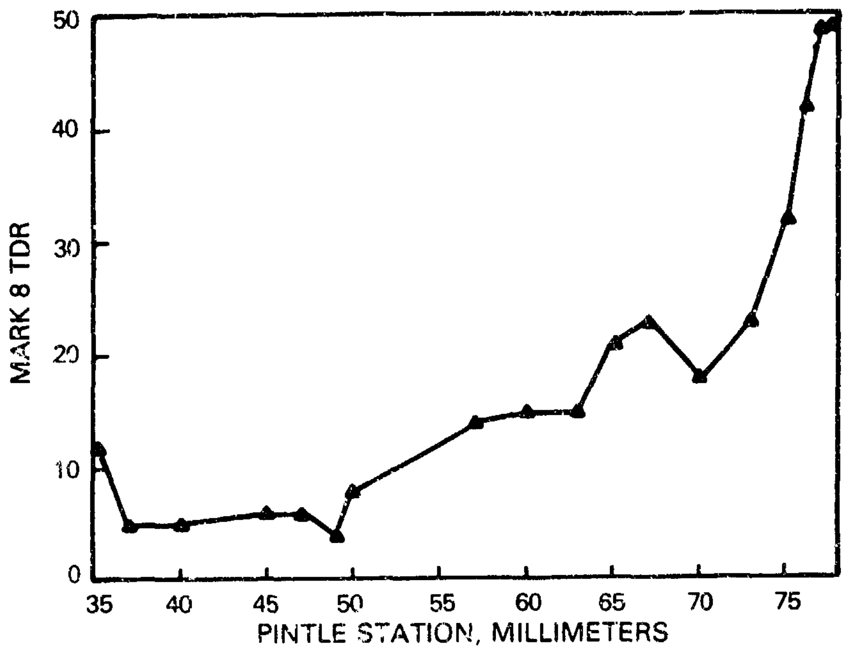


FIGURE 19. TDR RATING OF PINTLE B

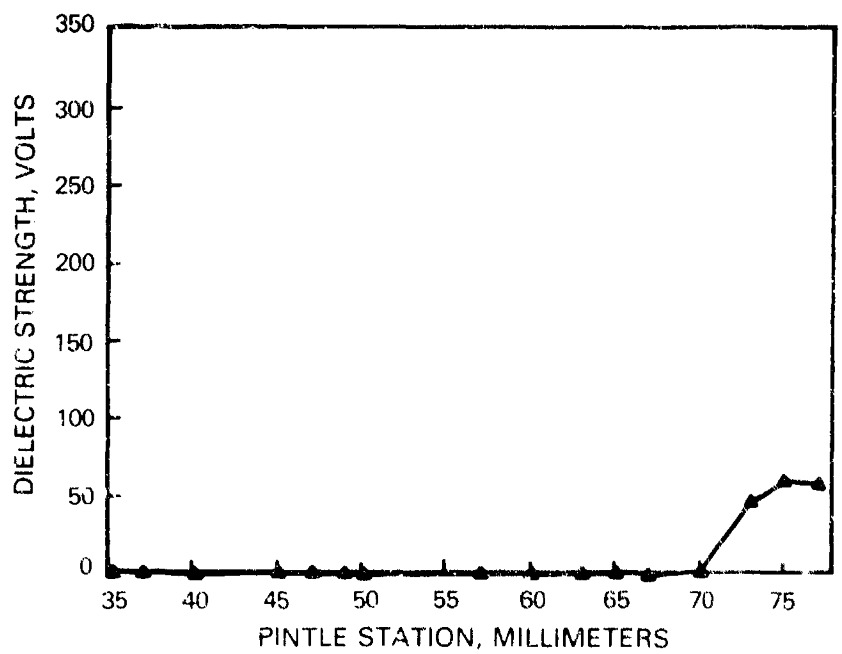


FIGURE 20. DIELECTRIC STRENGTH OF PINTLE B

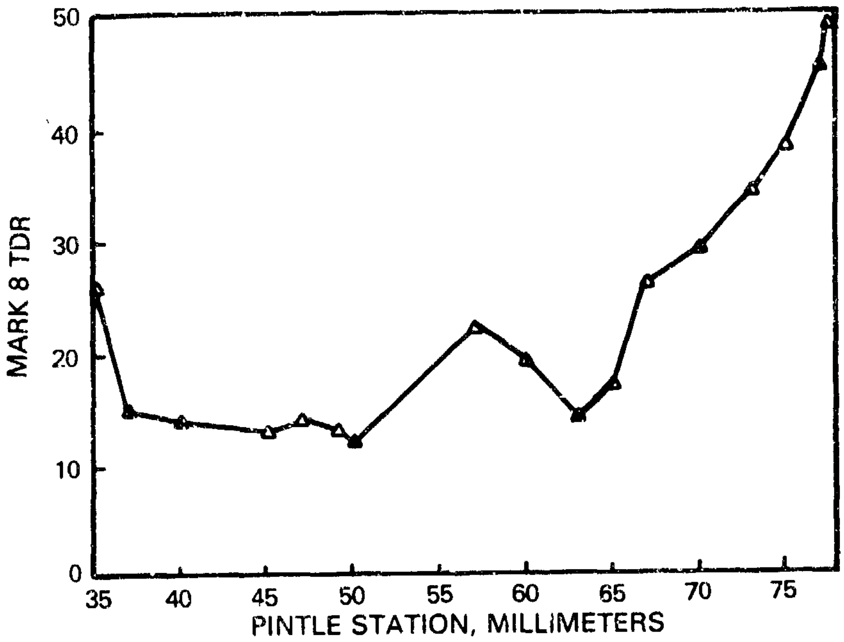


FIGURE 21. TDR RATING OF PINTLE C

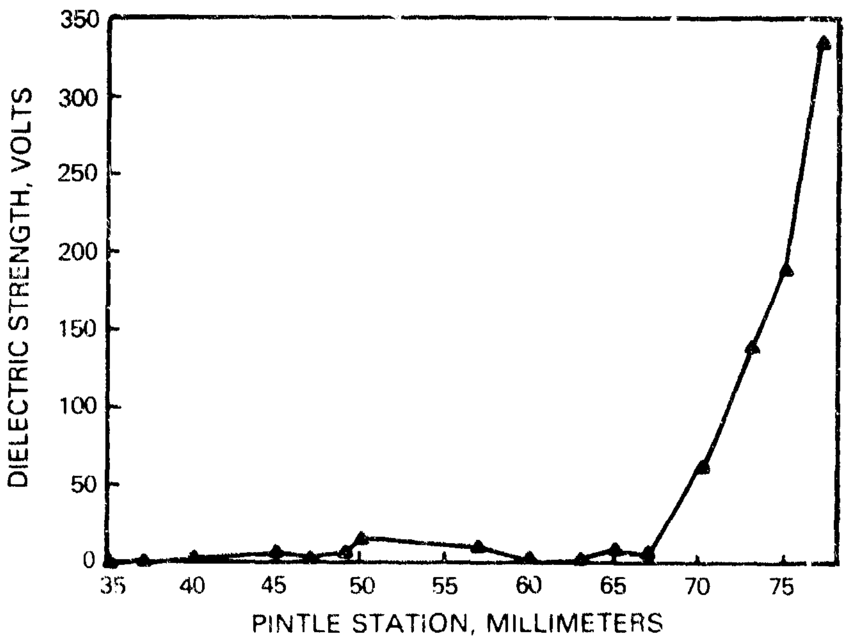


FIGURE 22. DIELECTRIC STRENGTH OF PINTLE C

Dielectric strength breakdown voltage testing is more selective in that the detected deposits must be of an electrically insulating nature such as the varnish-like deposits which are formed on JFTOT tubes. The dielectric testing of these pintles revealed that there are distinct differences between the pintles when evaluated for this type of deposit. Pintles A and B have only a slight buildup of electrically insulating deposits near the tip, while Pintle C has a very pronounced deposit near the tip area.

Navy Base Test Fuel--To evaluate the thermal oxidative stability of the Navy base test fuel No. 1 (AL-13279-F), three approaches were used, CLR-D hot engine test, injector fouling bench test, and jet fuel thermal oxidation test (modified for diesel fuel testing).

CLR-D Hot Engine Test The experimental results of the CLR-D hot engine test are presented in Table 19. Appendix A delineates the CLR-D Hot Test

TABLE 19. CRC VISUAL RATINGS OF INJECTOR PINTLE IN CLR-D HOT ENGINE TEST

Time at 317°C (603°F), Hr	Total Time, Hr	Time at 332°C (630°F), Hr	CRC Ratings Nonrubbing	Rubbing
2.3	3.0	0.7	0.4	1.55
5.6	9.5	3.3	0.6	1.25
8.0	16.0	4.0	0.6	1.55
9.5	22.5	5.0	0.6	1.95
12.5	29.0	3.5	0.4	1.95
16.5	36.0	3.5	0.4	2.05
23.3	44.0	2.0	1.0	2.40
28.3	50.0	1.0	1.0	2.40
30.8	52.5	0.0	1.0	2.55

Procedure. Table 19 lists the CRC visual ratings for the rubbing and nonrubbing parts of the pintle. Also listed in the table are the accumulated times at the test temperature for the rating, the total accumulated engine operating time for the

rating, and the time to reach the desired average liner temperature of 332°C (630°F). During the engine warm-up periods, the average liner temperature rapidly reached 260°C (500°F) (within 30 minutes) so that the average temperature over the total test duration was in excess of 260°C (500°F).

Engine failure occurred at a total accumulated test time of 52.5 hours. This corresponded to an accumulated time at 332°C (630°F) of 30.8 hours. The engine failure occurred due to excessive deposits in the ring belt area of the piston and the resulting sticking of the rings.

The results presented in Table 19 are plotted in Figure 23. The CRC rating increased only slightly at the end of the test. This is further indicated by the results of the JFTOT visual rating of the needle, performed at the same time as

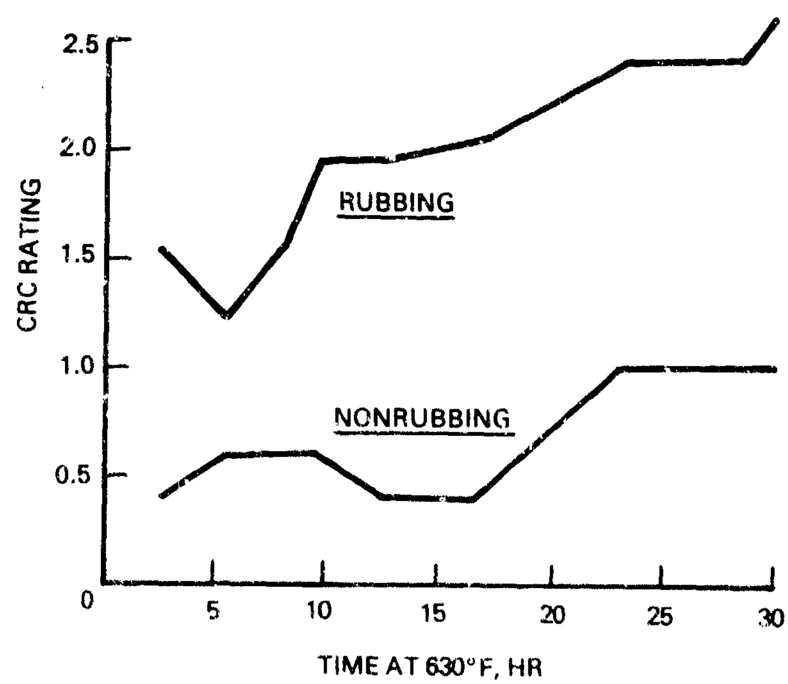


FIGURE 23. CRC VISUAL RATING VERSUS TEST TIME AT 332°C (630°)F

the CRC ratings. The JFTOT visual ratings were performed at 24 different locations along the length of the needle. The only locations where changes were observed were at the very tip of the needle. Even these changes were generally small and occurred late in the test. The results for the three tip locations are plotted in Figure 24. As with the CRC ratings, the major changes occurred during the final 10 hours of the test. Location 12 is the very tip of the needle.

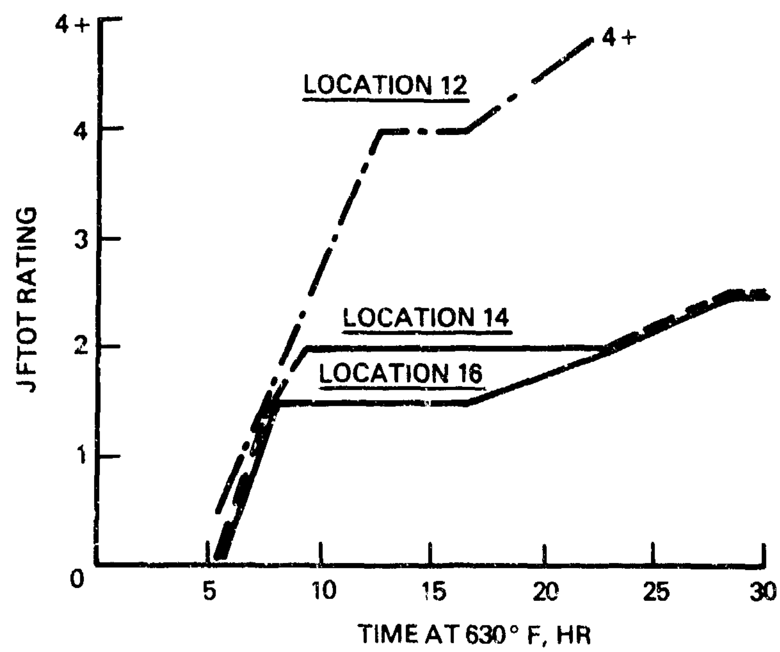


FIGURE 24. VISUAL RATING OF CRC INJECTOR NEEDLE VALVE USING JFTOT RATING SCALE

Injector Fouling Bench Tests--The injector fouling bench test (IFBT) was used to evaluate the Navy test fuel No. 1 (AL-13279-F). This fuel was run in two 40-hour tests; one with a Bosch injector and the other a Detroit Diesel injector.

Bosch Injector--Prior to the IFBT, the jerk pressure was set at 2500 psi, and the spray pattern was found to be very good. The injector's surfaces (rubbing and nonrubbing) were visually examined and found to be clean (zero demerits). After running for 40 hours at a fuel rate of 3 pounds per hour, the spray pattern was still very good, and the jerk pressure was 2475 psi. Using the CRC lacquer demerit scale, the total rubbing demerits were 2.40, and the nonrubbing were 5.10.

Using a special adapter, the pintle was inserted in the MARK 9 TDR for reflectance evaluation. The results of this evaluation are shown in Table 20.

The dielectric breakdown voltage measurements of the deposits on the pintle gave readings of zero, indicating the deposits were conductive.

Detroit Diesel Injector--All pretest checks (jerk pressure, airflow, fuel flow, leakdown dup, injector's surface inspection) were made. A 40-hour run was conducted on the IFBT. Post-test checks were nearly identical to the pretest conditions. Evaluations of the pintle using the CRC lacquer demerit scale on both the rubbing and nonrubbing surfaces showed the demerits to be relatively low, 3.00 and 2.25, respectively.

TABLE 20. MARK 9 TDR ON BOSCH PINTLE
(AL-13279-F Fuel)
(Test No. 21 After 40 Hours)

Station	Value
36	11
38	11
39	12
40	13
41	14
42	13
45	13
46	14
47	15
48	18
49	15
50	18
57	18
58	16
59	17
60	17
61	16
62	18
64	22
65	20
66	21
67	21
68	23
69	24
70	25
71	26
72	29
73	33
74	36
75	36
76	34

Figure 15 shows the relative size of the Bosch and Detroit Diesel (DD 6V-53T N70) injectors. As with the Bosch injector, the MARK 9 TDR was used to measure the deposits on the Detroit Diesel injector. Since this pintle is smaller than the Bosch's pintle, the number of stations were less. The results of this TDR evaluation are listed in Table 21.

Dielectric strength measurements were zero, indicating no varnish-type deposits.

Thermal Oxidation Tests--The Jet Fuel Thermal Oxidation Tester (JFTOT) was used to monitor the thermal stability of the Navy base test fuel (AL-13279-F) beginning in June 1984. Four sets of JFTOT tests were run and are

TABLE 21. MARK 9 TDR ON DETROIT PINTLE
(AL-13279-F Fuel)
(Test No. 8 After 40 Hours)

Station	Value
25	19
26	23
27	23
28	21
34	05
35	04
36	02
37	05
38	04
39	05
40	05
41	04
42	05
43	04
44	04

summarized in Table 22. The visual preheater deposit tube code ratings tended to worsen with storage time. This effect is shown graphically in Figure 25, which is a plot of JFTOT breakpoint temperatures (Code 3 deposit rating inception temperature) versus storage time. This indicates that the fuels' propensity to produce lacquer-like deposit during JFTOT testing is increasing with storage time.

The data in Table 22 also show a pronounced change in ΔP during the 9-month time frame of JFTOT testing. The pressure increases detected during JFTOT testing are caused by particulate plugging of the tester's 17-micrometer filter screen. Since the fuel is filtered just prior to the test (D 3241 test procedure), it can be assumed that plugging of the filter screen during test is an indication of

TABLE 22. THERMAL OXIDATION STABILITY TEST DATA FOR NAVY BASE TEST FUEL (AL-13279-F)

Date	Temp, °C (°F)	ΔP, mm of Hg	Preheater Deposit Code	Maximum TDR Spun Rating at mm
25 June '84	232 (450)	0 at 150 minutes	2	8 at 39
26 June '84	246 (475)	0 at 150 minutes	<3	21 at 37
26 June '84	252 (485)	0 at 150 minutes	<4	24 at 40
25 June '84	260 (500)	0 at 150 minutes	<4	23 at 32
25 July '84	243 (470)	2 at 150 minutes	3	19 at 39
25 July '84	249 (480)	0 at 150 minutes	4	21 at 38
16 Jan '85	232 (450)	0 at 150 minutes	2	9 at 14
17 Jan '85	235 (455)	5 at 150 minutes	<3	5 at 1
16 Jan '85	244 (472)	46 at 150 minutes	3	23 at 17
17 Jan '85	252 (485)	112 at 90 minutes	4	25 at 22
18 March '85	232 (450)	12 at 150 minutes	<3	17 at 45
20 March '85	235 (455)	15 at 150 minutes	<3	14 at 43
22 March '85	236 (457)	125 at 136 minutes	3	16 at 43
20 March '85	238 (460)	73 at 150 minutes	<4	22 at 42
19 March '85	246 (475)	125 at 137 minutes	4	26 at 49

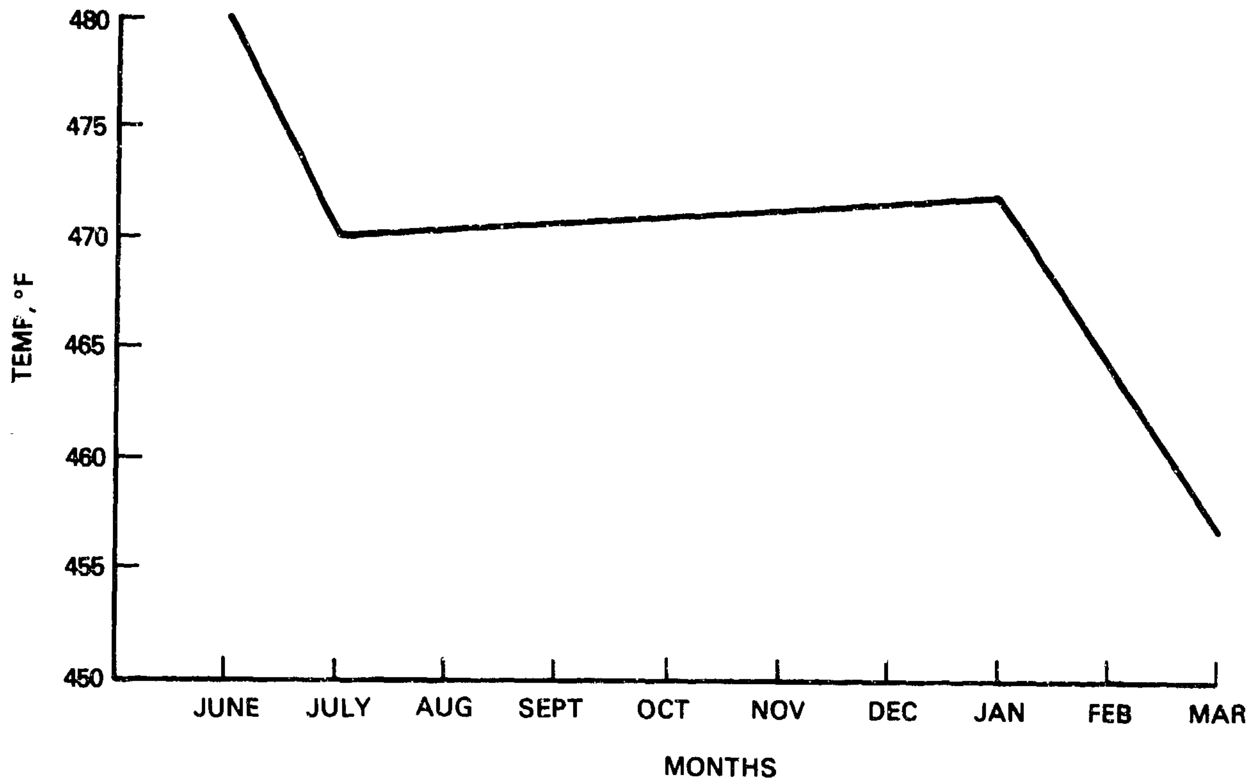


FIGURE 25. JFTOT BREAKPOINT TEMPERATURE (°F) VERSUS TIME

particulate formation during the JFTOT test. Figure 26 is a plot showing a substantial increase with storage time in the formation of screen plugging particulate at the breakpoint temperatures of the fuel. The combined effects of both lacquer-like deposits and particulate formation increasing with time show that this fuel's inherent thermal oxidation stability has significantly degraded during the 9-month storage period.

Not included in Table 22 are results of four test sets that were run during January 1985. These tests of the fuel were run specifically to generate deposits for another program involving development of an experimental method to measure deposit thickness using dielectric strength measurements. The results of these JFTOT tests are listed in Table 23. The dielectric strength technique is still in an experimental stage, but has produced good results with other fuels. The deposit produced from this test fuel was, however, impossible to evaluate by this technique because its electric properties are totally different from any other deposit tested in this way. All other deposits of lacquer-like material examined to date have been excellent electrical insulators, requiring approximately 300 volts per micrometer of deposit thickness to cause dielectric breakdown. The deposit produced by this

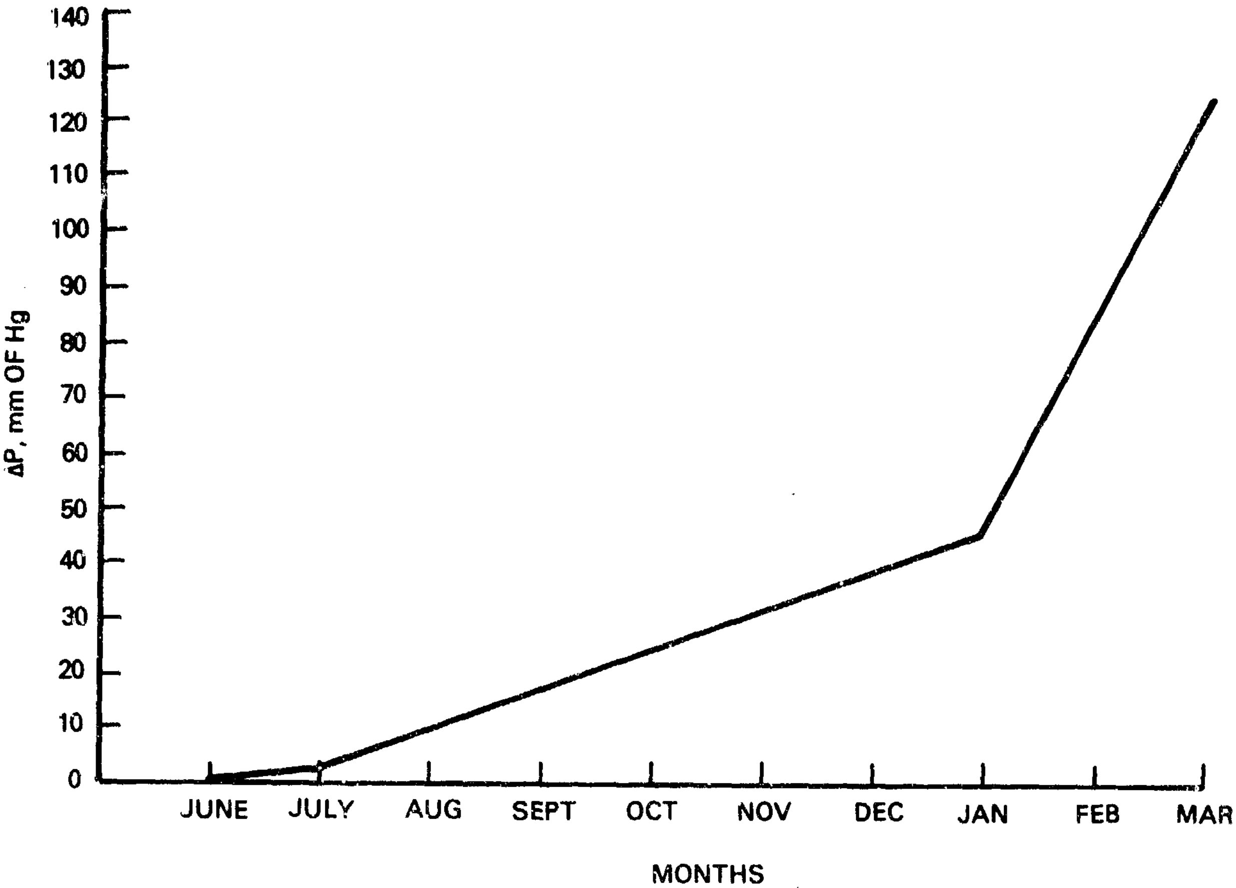


FIGURE 26. JFTOT ΔP (MM OF HG) AT BREAKPOINT TEMPERATURE

TABLE 23. THERMAL OXIDATION STABILITY TEST DATA FOR NAVY BASE TEST FUEL (AL-13279-F)

Date	Temp °C (°F)	ΔP, mm of Hg	Preheater Deposit Code	Maximum TDR Spun Rating at mm
24 Jan '85	260 (500)	245 at 78 minutes	>4	21 at 29
24 Jan '85	260 (500)	245 at 85 minutes	>4	18 at 30
25 Jan '85	260 (500)	245 at 87 minutes	>4	19 at 29
25 Jan '85	246 (475)	64 at 150 minutes	>4	17 at 24
28 Jan '85	246 (475)	62 at 150 minutes	>4	20 at 22
28 Jan '85	246 (475)	101 at 150 minutes	>4	17 at 21
29 Jan '85	232 (450)	3 at 150 minutes	2	5 at 17
29 Jan '85	232 (450)	2 at 150 minutes	2	7 at 16
30 Jan '85	232 (450)	2 at 150 minutes	2	4 at 15
30 Jan '85	218 (425)	1 at 150 minutes	<2	1 at 1
31 Jan '85	218 (425)	1 at 150 minutes	<2	5 at 1
31 Jan '85	218 (425)	1 at 150 minutes	<2	4 at 1

fuel is, however, somewhat electrically conductive. Auger spectrometer evaluation is being performed to determine which constituent of the deposit is degrading its insulating properties. The deposit also has an unusual visual appearance when examined in the lightbox used for JFTOT visual evaluation. The deposit showed a blue coloration with a powdery material on the surface which was removed by lightly rubbing the surface. Work is continuing within the dielectric test development program to determine the cause of the unusual appearance.

The results from both the injector fouling bench test and the CLR-D hot engine test indicate that the Navy Base Test Fuel (AL-13279-F) is stable to thermal oxidation, since all the various rating methods show relatively low amounts of the lacquer-like deposit formation.

Results from the Jet Fuel Thermal Oxidation Tester show that the fuels' thermal stability decreased during the storage period since breakpoint temperature decreased over the 9-month period. The fuels' instability may be more pronounced than was indicated by the above evaluations since the ratings are dependent on lacquer-like deposit formation and the test results are not necessarily affected by particulate formation. The JFTOT tests did detect significant pressure rise from particulate plugging of the filter screen during the later months of storage, and it must be concluded that the thermal instability of this fuel manifests itself as both lacquer-like deposit formation and particulate formation.

Summary of IFBT Development--In summary, injector nozzle rating methodology has been developed for the IFBT Bosch and Detroit Diesel injectors. The Bosch injectors are rated for pop-off pressure before and after test, and nozzle hole flow rating before and after test. The DD unit injectors are rated for injector pressure, fuel flow rate, leak down, and nozzle hole flow rating, all before and after test. The nozzle flow rating apparatus constructed was based on ISO standard 4010-1977(E).

The injector fouling bench test methodology needs to be expanded to cover higher temperatures and should be correlated with engine tests covering a wider temperature range than did the CLR-D hot engine test. An air-cooled test engine now in operation for lubricant development meets this requirement. The injectors in the

air-cooled engine are very similar in appearance to that of the CLR-D. A broader fuel matrix covering very unstable diesel fuel (including fluid catalytically cracked light cycle oil) should be employed to provide a large data matrix capable of being correlated to JFTOT-type test results employing not only visual rating methods but more importantly, both TDR Spun Rating and dielectric strength breakdown voltage for quantitation. Fuel test flow rate, temperature, test surface metallurgy, and fuel additive effects must be included in this evaluation.

IV. D 3241 JFTOT APPLICATION TO DIESEL FUEL

A. Measuring Thickness and Volume of Varnish-Like Fuel Deposits Via Dielectric Strength

1. Background

Many approaches have been evaluated for measurement of thermal oxidation-derived varnish-like fuel deposits. The JFTOT (ASTM D 3241) visual rating, using a lightbox with color standards, is the most commonly used method. While this visual rating method is suitable for go/no-go evaluation of fuel deposits, in most cases, it does have several inherent limitations. The rating scale has a very narrow dynamic range since a deposit can only be rated into one of six categories (0, 1, 2, 3, 4, 4+). The results are somewhat subjective, since each operator assigns the rating based on his individual perception of "best match" to the color standards. Abnormal and peacock (rainbow colored) deposits are rated as such. Color is not necessarily a good guide to deposit quantitation since a thin dark-colored deposit could be rated the same as a thicker but lighter colored deposit. Deposits with a matte surface can also appear darker than glossy surface deposits when compared visually. The greatest limitation of the visual rating is its inability to define actual thickness, volume, or mass of the deposit. Without at least one of these parameters being defined, it is almost impossible to determine activation energies or reaction rate information. A plot of reaction rate and activation energy would, if obtainable, allow much better judgments to be made as to the fuel's thermal-depositing potential or suitability for a particular application. This information would also be invaluable in studies of reaction mechanisms within the research laboratory environment.

To overcome some of the limitations in visual rating, a photo-optical measuring device known as the MARK 8A and MARK 9 Tube Deposits Rater (TDR) was produced by Alcor. The TDR eliminates the problem of operator subjectivity in color matching to the standards, and it allows a much wider rating scale of 0 to 50 measurement units. The TDR does not overcome any of the other problems common to visual rating such as the effects of deposit color or texture, and the TDR is incapable of directly producing deposit thickness, volume, or mass data.

In a 1973 report, it was noted that the light reflectance method for rating tube deposits was found to be more precise than the visual method.(10) Although there is a general relationship between the two rating methods, they are not exactly interchangeable. The visual rating method and the Alcor MARK 8A Tube Deposit Rater (TDR) were compared to each other and to measurements of the deposit thickness using an Auger Electron Spectrometer Ion Gun milling technique in a 1975 report.(11) Both the visual rating method and the MARK 8A TDR were found to correlate with deposit thickness measurements to a limited degree. Deposits that have a spectrum of colors (i.e., peacock or rainbow-type deposits) were found to be considerably thicker (one to three orders of magnitude) than Code 3 deposits. Calibration of the ion gun technique using carbon films provided a conversion factor of 0.028 angstroms/microamp seconds to calculate deposit thickness, i.e., thickness = 0.028 (milling rate in microamps) (milling time in seconds) for normal deposits, a Code 3 visual rating amounted to approximately 80 to 180 angstroms. Peacock deposits were found to be very thick, ranging as high as several thousand angstroms. For normal deposits, a Code 3 visual rating was equivalent to a TDR rating of about 17 or 18, ignoring peacock deposits.

The usefulness of TDR ratings for determining the activation energy of JP-5 fuels was demonstrated in a recent report.(12)

In 1977, Rolls Royce Ltd. (at Bristol, United Kingdom) investigated a burn-off technique for the measurement of the total carbonaceous material on a JFTOT tube.(13) Esso Research Center (Abingdon, England) extended the sensitivity of this method by developing tube-cleaning techniques and improved detection for measuring carbon dioxide in conjunction with Rolls Royce Ltd. in a recent report.(14) Deposit weights ranging from 40 to 250 μg of carbon are reported for

three fuels for which activation energies were calculated. The weight of carbon measured at the JFTOT breakpoint temperatures (Code 3 inception temperature) was found to be 40 and 70 μg for two different fuels. No correlation could be obtained between deposit weight and maximum TDR ratings, or integrated values of TDR response over the deposit area; however, for any given fuel, it was found that the weight of carbon and the maximum TDR values increased directionally with JFTOT test temperature. An approximate deposit thickness of 7500 angstroms was calculated based on a nominal weight of 100 μg of carbon deposited over a 20-mm length of JFTOT tube, assuming a density of 0.7 g/mL. Similar work done at Shell Research Ltd. using carbon burnoff pointed out two major drawbacks: the precision of the technique was stated to be poor and the burning off of the carbonaceous material present on new tubes tended to reduce the amount of material subsequently deposited during a test.(15) Rating tube deposits by carbon content, rather than the standard visual rating, did not improve the correlation between JFTOT and single-tube heat-transfer rig tests. Using carbon content, it was shown that fuel performance in the JFTOT is dependent on both flow rate and tube metallurgy. The fuel flow rate in the JFTOT and the use of aluminum test tubes could contribute to the poor correlation between the JFTOT and the "more reliable" test rigs that utilize higher flow rates and stainless steel test sections.(15)

To overcome some of the problems associated with the optical rating approaches, a new method of evaluating deposits has been developed using dielectric strength of tube deposits as a method for quantitation of these deposits.

2. Dielectric Strength Test Method

While investigating electrical resistivity as a possible approach to evaluating JFTOT fuel deposits, it was determined that the deposits behaved as an excellent electrical insulator. It appeared that this insulating property could potentially be explored as a means of measuring the deposit thickness as a function of the voltage required to "break down" the insulating property of the deposits. A bench test rig was assembled from available components for limited initial testing to determine the feasibility of this approach. The bench test rig consisted of a variable DC power supply covering the 0- to 550 volt range. The negative lead from the power supply was attached to the JFTOT test tube by a clip at a clean end of the tube. A

100K Ω resistor was placed in a series between the power supply and the positive lead to limit the maximum current flow; and to reduce potential shock hazard. The positive lead was then attached to a 1/16-inch diameter stainless steel wire which was mounted to a pivot. The stainless-steel wire served as an electrode which could be laid (perpendicular) across the JFTOT tube, in contact with the deposit; other spots could be checked by moving the electrode to another location on the tube. Since the round stainless steel wire was laid across the deposit, perpendicular to the round tube, only a small contact area was produced. A voltmeter was placed across the power supply, and a second voltmeter was placed across the 100K Ω resistor. Since no voltage would be detected as a voltage drop across the resistor until current flows between the electrode and the JFTOT tube, voltage detected across the resistor indicated break down of the deposit.

In operation, the power supply was set to 0 volts, the electrode placed across the spot to be tested, and the voltage was slowly increased while observing the voltmeter attached across the 100K Ω resistor. This meter would continue to read 0 volts regardless of actual voltage being applied to the deposit, until dielectric break down of the deposit occurs and current begins to flow. At that point, the meter jumps up scale and the power supply voltage which was required to break down the deposit is recorded from the voltmeter attached across the power supply. The supply voltage is then returned to 0 volts, the electrode moved to the next location, and the process repeated.

A group of used JFTOT tubes from a variety of previous tests was obtained; this was a "blind" group of samples since test conditions and fuel types were unknown. The tubes were visually rated for deposit, then tested for deposit dielectric strength. The dielectric tests produced results covering a surprisingly wide dynamic range. Tubes with Code 1 or 2 ratings generally produced dielectric readings of 0 to 10 volts, Code 3 tubes from 10 to 20 volts, Code 4 from 20 volts to approximately 400 volts and some tubes rated 4+ exceeded the limit of the power supply at 550+ volts. Since increase in breakdown voltage for an insulating material is in direct linear proportion to its thickness, the dielectric evaluation seemed to be resolving thickness variations covering two orders of magnitude. Based on the encouraging results of this initial evaluation of the dielectric technique, a matrix of JFTOT tests was defined to allow more detailed evaluation of the dielectric technique.

B. Measurement of Deposit Thickness by Metallurgical Cross-Sectioning of Entrapped Deposit

1. Background

As discussed previously, a variety of indirect approaches to evaluate deposits have been evaluated by different investigators. These approaches include the visual rating, TDR rating, Auger ion milling, determination of deposit carbon content, and dielectric strength measurement. Since all of these approaches are indirect, and all rely on certain prior assumptions of the deposit's material properties behavior, a more direct measurement approach was needed in order to calibrate the indirectly measured values of the various techniques to the directly measured deposit thickness. An approach was developed to allow entrapment of the deposit by enshrouding it in nickel plating. The tube can then be ground and polished in cross-section, and the deposit observed and measured at high magnification in an electron microscope.

2. Electron Microscope Measurement Technique

An approach which allowed a more direct physical measurement of the deposit thickness was to cut the test tube to remove the deposit's coated section, keeping careful record of the removed sections relative station locations and marking one end of the section with a reference mark for circumferential orientation. The section with the deposit intact was then cleaned by Freon washing, placed in a vacuum evaporation unit, and approximately 40 angstroms of silver was coated onto the tube outer diameter (OD) surface to serve as an electrically conductive film over the fuel deposits. The tube was then placed in an electrolytic nickel plating bath and approximately 0.05 mm of plating was deposited onto the thin silver coating. This process effectively trapped the fuel deposit between the aluminum tube and the silver/nickel plate. The tube section was then encapsulated in metallurgical mounting compound in an upright position to provide further backing and support for the plating layer during grinding and polishing operations. The location of the tubes circumferential reference mark was transferred to the OD of the mount, and the mount's thickness was measured and recorded to allow indexing to relative tube stations as the tube was ground down in increments to reach the stations of interest. Rough grinding to reach a particular location of

interest was done with 240 grit, followed by 400 and 600 grit. Polishing was then performed using 6-micron diamond polish followed by 1-micron diamond polish on smooth nylon cloth covered polishing wheels. No further polishing was performed as the desire in this case was to produce a relatively flat surface without the edge rounding that can sometimes occur when polishing is continued using finer abrasives on napped metallurgical polishing cloths.

Following the polishing operation, the circumferential reference location was scribed onto the polished face of the mount near the OD of the polished tube section. Several plastic replicas were then taken of the polished surface using Bioden replicating film before the mount was ground further to reach the next region of interest. The plastic replicas were then prepared in the usual manner for transmission electron microscope (TEM) examination by coating the plastic from a shallow angle with palladium for contrast enhancement of surface texture, then coating a carbon film evenly over the plastic to produce a carbon replica of the plastic replica's surface. The tube OD size was too large to allow fitting the entire replica of the tube into the TEM, so the carbon/plastic replica was cut into four arc-like quadrants for observation and the relative circumferential positions represented by each quadrant was recorded. The plastic replica was then dissolved away with solvent, leaving the intact carbon replica which was recovered on a copper TEM grid and placed in the TEM for examination. The fuel deposit could be easily identified in most cases as a narrow textured band trapped between the aluminum tube and the silver/nickel plating when observed at magnifications of 10,000X or greater. Photographs taken at appropriate magnifications allow thickness measurements to be taken directly from the photographs and the actual thickness determined by dividing the photograph's measured thickness by the magnification factor of the photographs. This technique worked quite well for fuel deposits that were > 1000 angstroms thick since the deposit thickness was relatively even over the observed field of view when this thickness of coating was observed. Thinner fuel deposit layers (<1000 angstroms) could be observed in the microscope but were more difficult to measure. The thinner deposits (<500 angstroms) were often irregular in thickness and in some cases discontinuous, making the determination of average thickness difficult.

This measurement technique, while somewhat time consuming, is probably the best overall means of determining deposit thickness since it allows visualization of the deposits and requires only that the TEM magnification ranges be properly calibrated. It is unsuitable for measuring tube deposits having visual ratings of Code 3 and lower, but can be used on Code 3 deposits if they are evenly distributed. It is a particularly useful approach if an Arrhenius-type plot of the deposit thickness versus temperature is to be produced for a series of tests producing deposits of Code 3 and greater. If the Arrhenius-type plot produces a linear slope, the line can be extrapolated into the less than visual Code 3 thickness ranges with reasonable expectations of accuracy.

The specimens can also be examined directly in a scanning electron microscope (SEM) without the tedious replication steps inherent in TEM preparations. The SEM must, however, be capable of crisp image resolution up to 20,000X magnification, and backscatter detection is desirable to improve contrast between the organic deposit and the metals.

C. Test Matrix

1. Purpose and Approach

To evaluate the dielectric method of deposit measurement and to allow comparison of this method to other rating approaches, a fuel test matrix was established using four primary fuels: Cat 1-H engine reference fuel, 1-percent sulfur fuel (MIL-F-46162), a commercial Jet A-1, and a diesel reference control fuel. Two secondary fuel blends were also tested; Jet A-1 spiked with 5 vol% tetralin and Jet A-1 spiked with tetralin and thiophene at 5 vol% each.

The six fuels were each tested at five temperature ranges on the JFTOT tester (D 3241), giving a total of 30 fuel/temperature variables. Each of the 30 test conditions was run in triplicate so the total matrix involved testing and evaluation of 90 JFTOT tubes.

The triplicate testing of each test condition was performed for several reasons. It allowed observation of the repeatability of results from the triplicate tests, and if

some scatter were noted in the data, the averaging of results from the triplicate tests could more closely approximate the norm for the test conditions. Having tubes from triplicate tests also allowed backup tubes to be available if problems were encountered during evaluation of deposit using destructive evaluation techniques (i.e., sectioning, Auger ion milling, etc.).

The five test temperatures for each fuel were selected in an attempt to produce one JFTOT test near the fuel's breakpoint (visual Code 3 inception temperature), two tests below the breakpoint temperature, and two tests above the breakpoint temperature.

After testing, each of the 90 JFTOT tubes was given a detailed evaluation by visual rating method, TDR rating method, and the dielectric breakdown method. Selected tubes and locations were then sectioned and examined by electron microscope to measure deposit thickness, and other locations were selected to allow limited evaluation of Auger spectrometer/ion milling as a means of determining deposit thickness.

To reduce any scatter that might be introduced due to surface finish variations of the as-received aluminum JFTOT tubes, all the tubes were polished prior to testing with 1-micron diamond compound to produce a consistent surface finish. They were then cleaned in an ultrasonic bath, rinsed with acetone, rinsed with heptane, and dried. Tube indexing was indiscriminate after the JFTOT test for this matrix; subsequent JFTOT tests used an indexing method which provided for a zero degree scribe mark on the end of test tube (facing the instrument operator) or 180 degrees from the face of the JFTOT instrument behind the test tube specimen.

2. Matrix Results and Comparison of Rating Techniques

a. General

The measurements data for the 90 test tube matrix are provided in Appendix C. The test temperatures selected to produce deposits of less than visual Code 3 were, in some cases, too low since they produced no detectable deposit. The ranking of

the four primary fuels by breakpoint temperature was consistent with expected results. The 1-percent sulfur diesel fuel had the lowest breakpoint temperature, followed by Cat 1-H, and the diesel control, with Jet A-1 having the highest breakpoint temperature.

The two secondary fuel blends of Jet A-1 spiked with tetralin or tetralin plus thiophene produced abnormal deposits at lower testing temperatures (as opposed to higher test temperatures) which made a fair comparison of the rating techniques impossible. These abnormal deposits were not the normally encountered varnish-like deposits, they appeared as a "light blue" or "peach-colored" deposit which loosely adhered to the tube, and, in most cases, could be removed by lightly wiping the tube with a cloth. The presence of this abnormal deposit produced significantly higher ratings with visual and TDR than were obtained by dielectric. At higher temperatures, these fuel blends produced normal varnish-like deposits which affected visual, TDR, and dielectric ratings in the normal expected manner. Data obtained from these fuels are included in Appendix C, but is not included in the following comparison of testing techniques due to the "abnormal" nature of the lower temperature deposits produced by these secondary spiked fuel blends.

b. Dielectric Breakdown Method

Based on the data presented in Figure 27, for the 1-percent sulfur fuel at four D 3241 test temperatures, one micrometer of deposit thickness is shown to equate to a dielectric strength breakdown voltage of approximately 350 volts.

A linear regression analysis was performed on the dielectric versus optical thickness measurements of the 1-percent sulfur reference fuel data. These 36 data values are listed in Table 24. The dielectric voltage measurements were converted to micrometers by dividing each value by 350 (see column A in Table 24). The derived linear regression model for this set of data is as follows:

$$\text{Dielectric Thickness} = (0.0004475) + (0.9774181 \times \text{Optical Thickness})$$

A coefficient of determination (R^2) equal to 0.9678 and a standard error of 0.04967 were calculated from this regression model.

TABLE 24. DIELECTRIC BREAKDOWN VOLTAGE AND OPTICAL THICKNESS MEASUREMENTS

Dielectric Breakdown*			Optical Thickness, µm	Dielectric Breakdown*			Optical Thickness, µm
	Thickness, µm				Thickness, µm		
Volts	A	B		Volts	A	B	
7.6	0.022	0.023	0.06**	250.4	0.715	0.766	0.68**
28.0	0.080	0.086	0.06**	181.8	0.519	0.556	0.68**
9.3	0.027	0.028	0.06**	244.0	0.697	0.746	0.73**
25.4	0.073	0.078	0.06**	(556.0	1.59	1.700	1.90)***
2.6	0.007	0.008	0.00**	431.0	1.59	1.318	1.22**
0.0	0.000	0.000	0.09**	244.8	0.699	0.749	0.77**
2.5	0.007	0.008	0.09**	5.1	0.015	0.016	0.00
39.8	0.114	0.122	0.09**	3.1	0.009	0.009	0.00
32.2	0.092	0.098	0.09**	0.0	0.000	0.000	0.00
43.9	0.125	0.134	0.09**	3.0	0.009	0.009	0.00
42.4	0.121	0.130	0.12**	6.4	0.018	0.020	0.00
75.7	0.216	0.231	0.19**	0.0	0.000	0.000	0.00
70.0	0.200	0.214	0.19**	0.0	0.000	0.000	0.00
86.2	0.246	0.264	0.23**	4.3	0.012	0.013	0.00
118.6	0.339	0.363	0.37**	10.6	0.030	0.032	0.05
118.6	0.339	0.363	0.32**	21.8	0.062	0.067	0.05
105.2	0.301	0.322	0.32**	12.4	0.035	0.038	0.00
32.8	0.094	0.100	0.09**	0.0	0.000	0.000	0.00
12.7	0.036	0.039	0.05**	0.0	0.000	0.000	0.00
47.4	0.135	0.145	0.10**	0.0	0.000	0.000	0.00
114.4	0.327	0.350	0.32**	0.0	0.000	0.000	0.00
130.6	0.373	0.399	0.32**	5.6	0.016	0.017	0.00
103.7	0.296	0.317	0.32**	5.7	0.016	0.017	0.00
146.1	0.417	0.447	0.45**	0.0	0.000	0.000	0.00
179.1	0.512	0.548	0.54**	27.5	0.079	0.084	0.06
188.8	0.539	0.577	0.58**	1.9	0.005	0.006	0.00
256.5	0.733	0.784	0.67**	5.2	0.015	0.016	0.00
24.1	0.069	0.074	0.08**	47.3	0.135	0.145	0.1
156.4	0.447	0.478	0.32**	44.8	0.128	0.137	0.1
106.4	0.304	0.325	0.32**	0.0	0.000	0.000	0.06
95.0	0.271	0.291	0.32**	0.0	0.000	0.000	0.00
0.0	0.000	0.000	0.00	74.3	0.212	0.227	0.18
3.0	0.009	0.009	0.00	56.1	0.160	0.172	0.2
1.1	0.003	0.003	0.00	105.3	0.301	0.322	0.3
4.1	0.012	0.013	0.00	156.4	0.447	0.478	0.4
0.0	0.000	0.000	0.00	203.9	0.583	0.624	0.8
0.0	0.000	0.000	0.00	158.8	0.454	0.486	0.7
0.0	0.000	0.000	0.00	34.4	0.098	0.105	0.2
5.0	0.014	0.015	0.00	65.7	0.188	0.201	0.2
0.0	0.000	0.000	0.00	100.3	0.287	0.307	0.3
53.1	0.152	0.162	0.09	93.4	0.267	0.286	0.3
0.0	0.000	0.000	0.00	155.4	0.444	0.475	0.5
3.6	0.010	0.011	0.05	285.1	0.815	0.872	0.7
94.4	0.270	0.289	0.22	162.3	0.464	0.496	0.6
50.6	0.145	0.155	0.15	155.0	0.443	0.474	0.6

* A = Volts divided by 350; B = Volts divided by 327.

** 1-percent sulfur reference fuel.

*** 1-percent sulfur reference fuel; Upper limit of voltmeter - this data point was deleted from regression analyses.

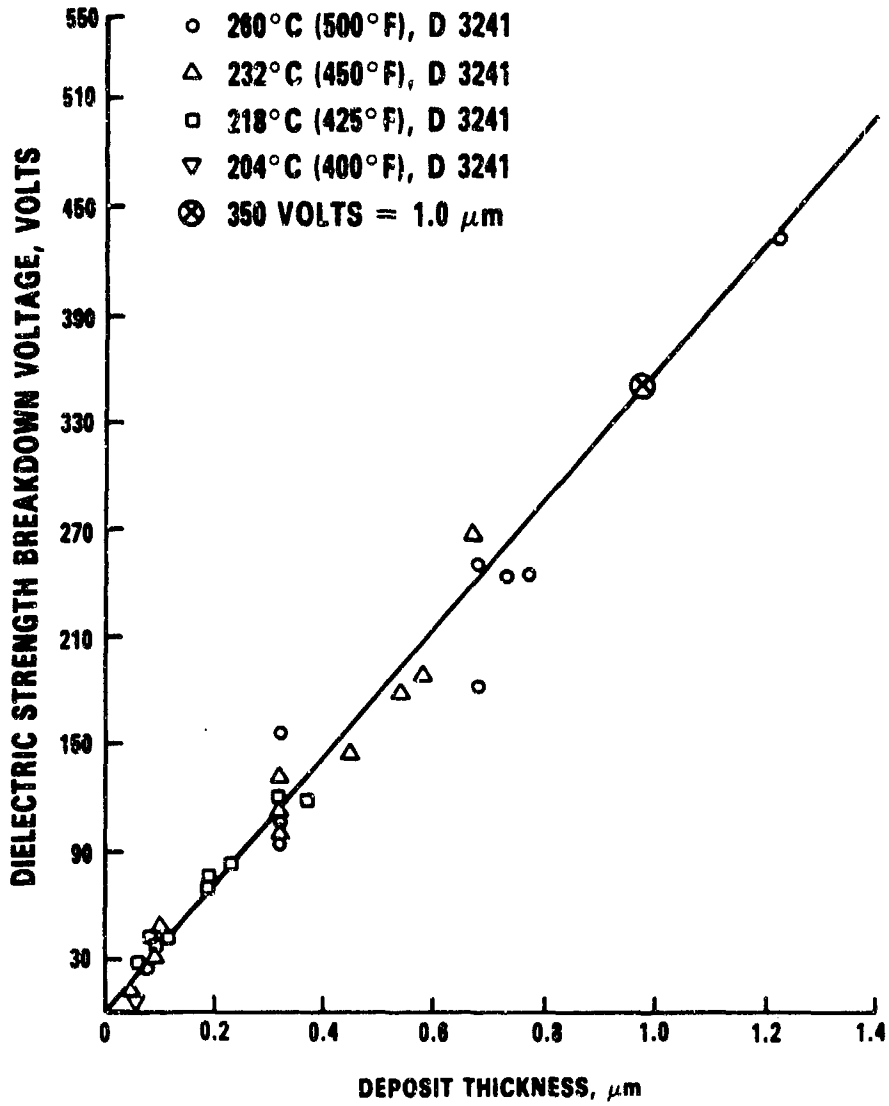


FIGURE 27. DIELECTRIC STRENGTH BREAKDOWN VOLTAGE, VOLTS

In order to determine whether the dielectric and optical thickness measurements are comparable in measuring the deposits on the test tubes for the 1-percent sulfur reference fuel data, one can test the derived parameter estimates of the linear regression equation to determine if the slope is one and the intercept is zero (i.e., dielectric = optical measurement). From the results listed in Table 25, one would accept the hypothesis that the intercept is zero ($\alpha = 0.97$ level of significance) and would reject the hypothesis that the slope is zero ($\alpha = 0.0001$ level of significance). However, to test whether the slope is equal to one, the following test statistic can

TABLE 25. LINEAR REGRESSION RESULTS

Variable	Parameter Estimate	Standard Error	t for H_0: Parameter = 0	Prob >|t|
Intercept	0.007426	0.009296	0.790	0.4314
Optical Thickness	0.929164	0.024955	37.234	0.0001

be calculated using the derived parameter estimate for the slope and its standard error:

$$t = \frac{\text{Hypothesized Slope - Estimated Slope}}{\text{Standard Error}}$$

$$t = \frac{1.0 - 0.9774181}{0.0305618} = 0.7388930$$

Since the calculated t-value falls below the tabulated t-distribution value of 2.0322 (evaluated at n-2=34 degrees of freedom and $\alpha/2 = 0.025$ significance level for a two-tailed test), the hypothesis that the slope = 1.0 is accepted at the 95 percent confidence level. Verifying the assumption that 1 micrometer of deposit thickness is approximately equal to 350 dielectric strength breakdown volts for the 1-percent sulfur reference fuel data.

A linear regression analysis of all dielectric voltage and optical thickness data generated in the program (Table 24) was performed to investigate the sensitivity of the conversion factor of 350 (based on Figure 27 for the 1-percent sulfur fuel) when converting dielectric volts to micrometers. The results of the regression analysis are listed in Table 26. The derived linear regression model for this set of data is as follows:

Dielectric Thickness = (0.0067618) + (0.9208891 x Optical Thickness)

From the results listed in Table 26, one would accept the hypothesis that the intercept is zero ($\alpha = 0.35$ level of significance). To test whether the slope is equal to one, the following test statistic is used:

TABLE 26. LINEAR REGRESSION RESULTS USING DIELECTRIC (MICROMETERS*) VERSUS OPTICAL THICKNESS MEASUREMENTS FOR ALL DATA

Dependent Variable = Dielectric (micrometers)

Variable	Parameter Estimate	Standard Error	t for H_0: Parameter = 0	Prob >|t|
Intercept	0.0067618	0.0072025	0.939	0.35044
Optical Thickness	0.9208891	0.0223030	41.290	0.0001

*Micrometers = Volts/350

$$t = \frac{1.0 - 0.9208891}{0.0223030} = 3.5471$$

Since the calculated t-value falls above the tabulated t-distribution value of 1.988 (evaluated at n-2=87 degrees of freedom and $\alpha/2 = 0.025$ significance level for a two-tailed test), the hypothesis that the slope equals one is rejected at an α - 0.05 level of significance. Therefore, one can conclude that the slope of the regression equation is not equal to one. Moreover, the dielectric thickness measurements tend to be lower than the optical thickness measurements.

This conversion factor can be investigated by deriving a no-intercept linear regression model for the entire fuel data listed in Table 24. The results of this regression analysis are listed in Table 27, and the model is

Dielectric (volts) = 326.875 x Optical Thickness (micrometers)

TABLE 27. LINEAR REGRESSION RESULTS USING DIELECTRIC (VOLTS) VERSUS OPTICAL THICKNESS MEASUREMENTS

Dependent Variable = Dielectric (volts)

Variable	Parameter Estimate	Standard Error	t for H_0: Parameter = 0	Prob >|t|
Optical Thickness	326.87513	6.103277	53.557	0.0001

Thus, it appears that the best factor estimate is 327 for converting volts to microns for the data in Table 24. Table 28 lists the results of the regression model using the converted dielectric voltage measurements (dielectric (micrometers) = dielectric (volts)/327). From the results in Table 28, one would accept the hypothesis that the intercept is zero ($\alpha = 0.35$ level of significance). To test whether the slope is equal to one, the following test statistic can be evaluated:

$$t = \frac{1.0 - 0.9856611}{0.0238717} = 0.6007$$

TABLE 28. LINEAR REGRESSION RESULTS FOR DIELECTRIC (MICROMETERS*) VERSUS OPTICAL THICKNESS MEASUREMENTS FOR ALL DATA

Dependent Variable = Dielectric (micrometers)

Variable	Parameter Estimate	Standard Error	t for H_0: Parameter = 0	Prob > |t|
Intercept	0.0072374	0.0077092	0.939	0.3504
Optical Thickness	0.9856611	0.0238717	41.290	0.0001

Since the calculated t-value falls below the tabulated t-distribution value of 1.988 (n-2=87 degrees of freedom and $\alpha/2 = 0.025$ significance level for a two-tailed test), the hypothesis that the slope is 1.0 is accepted at the 95-percent confidence level.

Figure 28 illustrates the linear regression fit to the data using the parameter estimates in Table 28. It should be noted that all the other data in this report continues to use 350 volts equal to one micrometer because the value is more conservative and is based on the large data set obtained for one test fuel at four different JFTOT test temperatures.

The dielectric results from the four quadrants at each station location were averaged to produce an average dielectric value around the tube for each station location. The highest value thus obtained for each tube was defined as the worst case dielectric value for that tube and is indicative of the maximum thickness encountered around the tube at the various stations tested. The worst case values

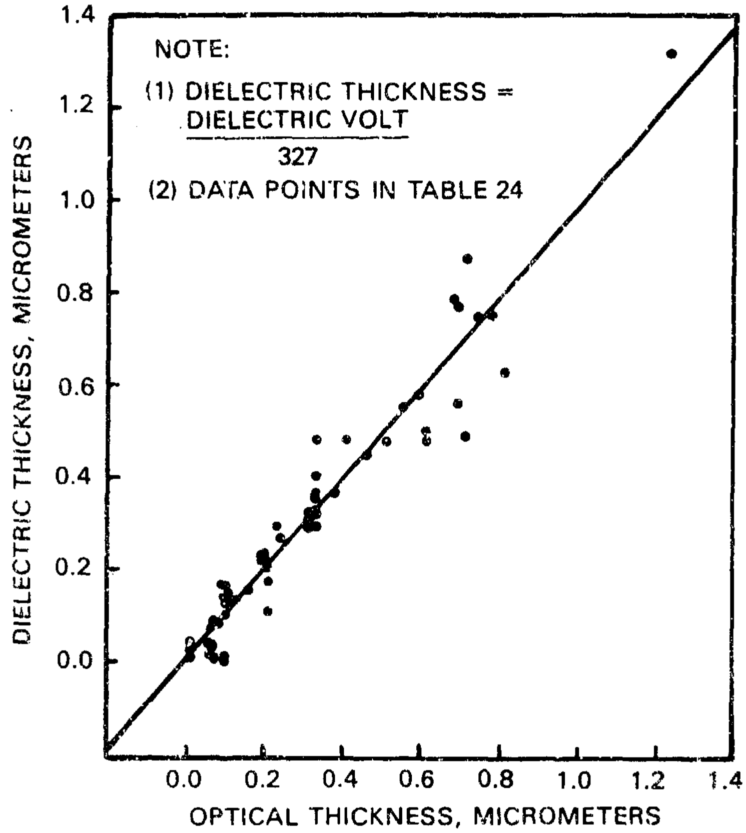


FIGURE 28. LINEAR REGRESSION FIT FOR DIELECTRIC THICKNESS (MICROMETER) VERSUS OPTICAL THICKNESS MEASUREMENTS FOR ALL FUEL DATA

for the triplicate tests were averaged to produce a dielectric breakdown voltage representative of each temperature at which a fuel was tested. These worst case averages for the various testing temperatures of the four primary fuels are presented in Figure 29 as a plot of the natural log of dielectric voltage versus the inverse of absolute temperature.

The deposit thickness should be proportional to the product of reaction rate and reaction time. Since the time is constant for all of the tests, the deposit thickness should be directly proportional to the reaction rate. If the dielectric breakdown voltage is a valid expression of deposit thickness, then the plots shown in Figure 29 should follow the Arrhenius relationship and produce straight lines. The fact that the plots are linear, combined with the correlations shown between measured

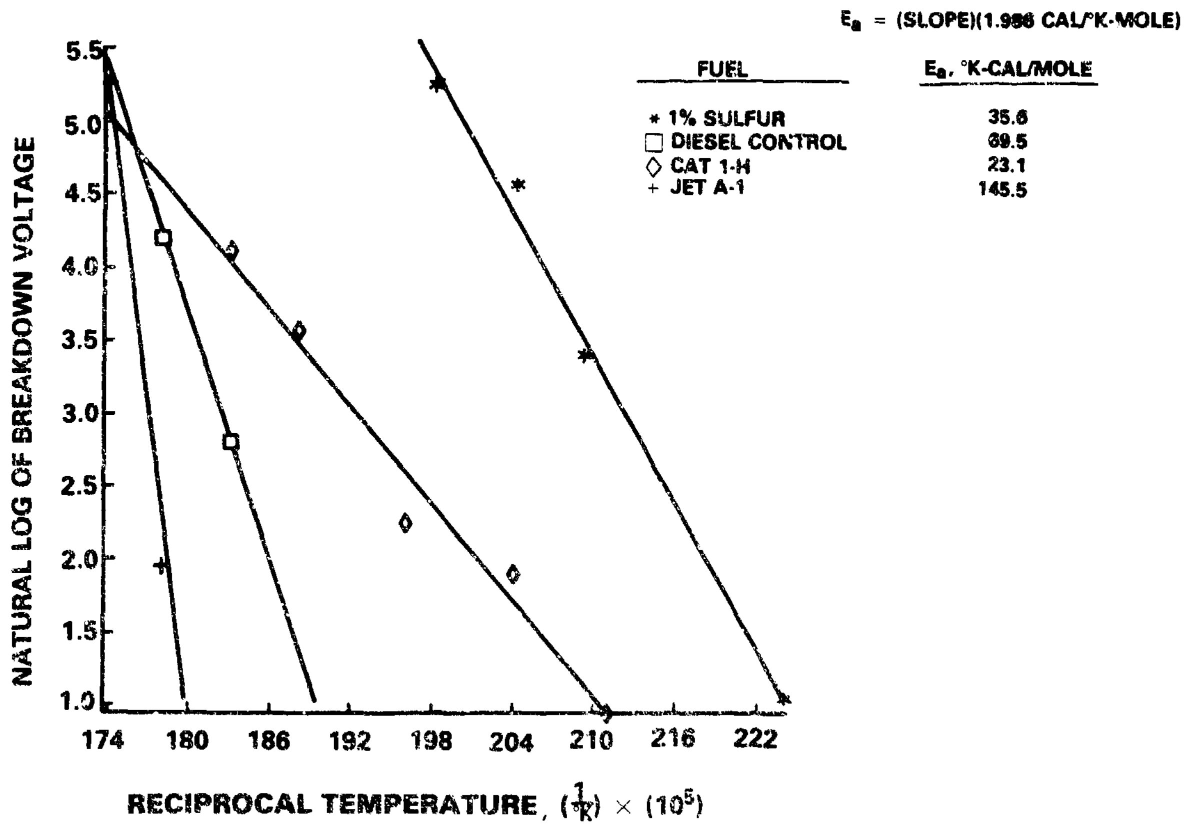


FIGURE 29. PLOT ILLUSTRATING REACTION RATES

thickness and dielectric thickness in Figure 27, indicate that dielectric breakdown voltage is a usable tool for determination of deposit thickness. Also provided in Figure 29 are the calculated energy of activation values. The E_a values in Figure 29 are much higher than other reported values which range from 7 to 22 kcal/mode.(12,14)

Figure 30 represents the worst case average values for the same four fuels plotted as breakdown voltage versus temperature in degrees C. The dotted line represents the Code 3 breakpoint established for the fuels by visual rating. An interesting observation can be made from this plot. If the voltages do represent thickness, then a visual Code 3 deposit at 204°C (400°F) is actually three times thicker than a visual Code 3 at 232°C (450°F) and nine times thicker than a Code 3 at 266°C (510°F). This, if true, could be due to the deposit forming with a darker coloration

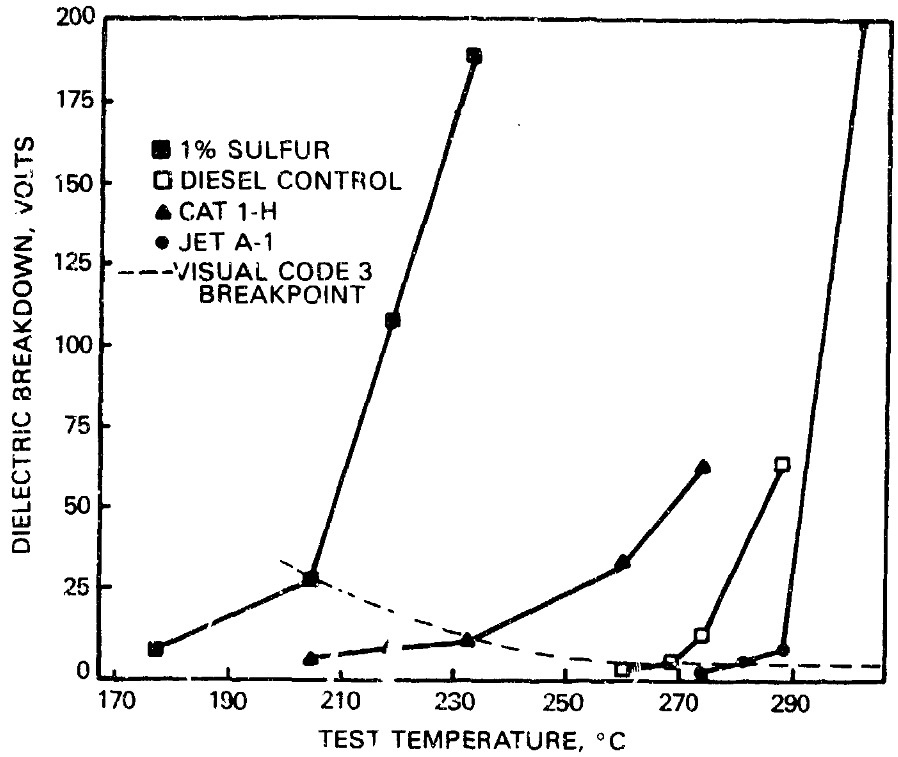


FIGURE 30. HIGHEST DIELECTRIC BREAKDOWN VOLTAGE (AVERAGE 3 TUBES) VERSUS TEST TEMPERATURE

at the higher test temperatures which would result in more severe visual rating for a given thickness. More extensive testing would be required to determine if this observation shows a trend toward more severe visual ratings as temperature is increased, or if the pattern is just an anomaly of this particular data set.

The major advantage of the dielectric breakdown approach to deposit evaluation is the ability to quantitate results. For any homogenous insulating material, the changes detected in breakdown voltage are directly proportional to changes in thickness. Thus, a doubling of voltage when comparing one area to another indicates that the higher voltage zone is twice the thickness of the lower voltage zone. All testing done to date indicates that "normal appearing" varnish/lacquer-like deposits and "peacock" deposits can be quantitated using dielectric breakdown techniques. Based on the data presented in Figure 27, for the 1-percent sulfur fuel at four D 3241 test temperatures, one micrometer of deposit thickness equates to a dielectric strength breakdown voltage of approximately 350 volts. Since thickness can be evaluated by this technique, it is also possible to determine approximate volume of deposits on the JFTOT tube if thickness has been measured at a sufficient number of points on the tube.

To determine volume of deposit for the tubes in this test matrix, longitudinal traverses were made along each tube, taking a voltage reading every 2 millimeters along the length (Appendix C). Four individual traverses were made, rotating the tube 90 degrees each time a traverse was completed. This gave thickness information representing four quadrants around the tubes' circumference. It is important to generate thickness information from at least these four locations around the tube since the deposit is sometimes thicker on one side of a tube, and the thickness distribution around the tube must be known to calculate volume. Table 29 summarizes volumes of deposit calculated for all JFTOT tubes in the matrix which produced detectable amounts of deposit. The method used to calculate the volumes of deposit is explained in Appendix D. The volumes listed under each individual quadrant in Table 29 represent the deposit volume that would be calculated if only the one quadrant had been measured and even distribution around the tube was assumed. The volumes listed under "average" in Table 29 were calculated based on average thickness for the four quadrants at each 2-mm station and are thus a more accurate presentation of total volume present on the tube. This table illustrates not only the expected increase of deposit volume as test temperatures are increased for each fuel, but also shows the variations in deposit formed in each quadrant, as well as variations that were encountered between the triplicate tests at each temperature. Similar variations between triplicate tests were noted by visual rating and TDR rating. The cause of this occasional variation in triplicate tests is unknown. (Note: D 3241 repeatability and reproducibility data are not available.)

Figure 31 is a plot of the average thickness by breakdown voltage at each 2-mm station, and TDR spun rating down the length of the test tube (Number 524T) at each 2-mm station for the 1 percent sulfur test fuel run by D 3241 at 218°C (425°F). Also provided in Figure 31 is the visual code rating at each 2-mm station. Figure 32 visually compares the average deposit thickness at each 2-mm station as an area plot to the plot of the dielectric strength breakdown voltage at each 2-mm station in each of the four quadrants given by angles in degrees, i.e., 0°, 90°, 180°, and 270°. This three-dimensional plot is informative in showing the deposit thickness variation around the test tube and down the length of the test tube.

Plots similar to Figure 32 are provided in Appendix D at selected D 3241 test temperatures for all six of the test matrix fuels.

TABLE 29. VOLUME OF DEPOSIT BASED ON DIELECTRIC STRENGTH BREAKDOWN VOLTAGE

Fuel Code	D 3241 Test Temperature, °C (°F)	Test No.	Visual Code Rating	Calculated Volume of Deposit, cm³ x 10⁻⁷* 0°	90°	180°	270°	Average
1% Sulfur (AL-13619-F)	177 (350)	513T	0	18	11	18	25	18
	177 (350)	515T	0	0	0	0	0	0
	177 (350)	521J	0	8	16	35	24	19**
	204 (400)	503J	3P	138	122	121	176	138**
	204 (400)	512J	3P	160	166	128	199	163
	204 (400)	514J	3P	202	92	191	173	165
	218 (425)	504T	>3P	496	582	374	541	498
	218 (425)	519J	>3P	582	608	510	576	569
	218 (425)	524T	>3P	503	416	505	510	483**
	232 (450)	502T	4	658	710	774	701	711
	232 (450)	517T	4	1089	1130	1062	1354	1159
	232 (450)	520T	4	923	1007	950	1188	1022**
	260 (500)	518J	>4	3033	3467	3592	2755	3268**
	260 (500)	501J	>4	3215	3337	3568	3386	3377
	260 (500)	516J	>4	2072	2429	2065	1536	2030
Cat 1-H (AL-13618-F)	204 (400)	496J	0	11	0	1	7	5
	204 (400)	505J	0	18	3	9	16	12
	204 (400)	508J	0	2	3	13	4	6**
	218 (425)	495J	>2P	19	8	31	42	25
	218 (425)	506T	>2	12	54	15	25	26**
	218 (425)	507T	>2	51	45	44	52	48
	232 (450)	493J	3	36	20	59	25	35
	232 (450)	498T	3	44	35	40	40	41**
	232 (450)	511J	3	30	40	71	88	58
	260 (500)	494T	>4	83	86	135	91	99
	260 (500)	509J	>4	112	91	109	242	139
	260 (500)	510T	>4P	104	115	177	121	128**
	274 (525)	497J	>4P	163	227	179	284	218**
	274 (525)	499J	>4P	171	338	310	244	266
	274 (525)	500T	>4P	195	150	198	297	215
Diesel Control (AL-13630-F)	274 (525)	1	>3	32	21	52	39	36
	274 (525)	2	>3	8	43	15	38	26**
	274 (525)	3	>3	31	5	8	13	14
	288 (550)	1	4	176	325	207	117	206**
	288 (550)	2	4	188	225	159	202	194
	288 (550)	3	4	249	275	262	229	254
Jet A-1 (AL-13623-T)	281 (538)	531J	>3	4	8	5	2	5
	281 (538)	532T	>2	2	1	4	4	3**
	281 (538)	533J	[illegible]	2	1	2	1	1
	288 (550)	526T	>4	13	6	5	14	9
	288 (550)	528T	>4	25	11	30	12	20
	288 (550)	538J	>4	8	26	24	10	17**
	302 (575)	534T	>4	714	724	742	669	717
	302 (575)	535T	>4	517	493	488	659	539
	302 (575)	536J	>4	454	596	616	615	575**
Jet A-1 + Tetralin (AL-13633-T)	288 (550)	543J	>4	214	214	214	231	219**
	288 (550)	544T	>4	255	115	238	252	215
	288 (550)	550T	>4	241	243	193	297	244
Jet A-1 + Tetralin + Thiophene (AL-13636-T)	260 (500)	564J	1	1	0	11	6	5**
	260 (500)	571T	1	0	0	0	0	0
	260 (500)	573T	1	0	0	0	0	0
	274 (525)	565J	>2	60	23	74	111	67
	274 (525)	574J	>2P	13	14	15	62	26**
	281 (538)	566J	3P	182	131	117	113	136**
	281 (538)	567T	3P	176	143	194	308	205
	281 (538)	578T	3P	47	86	71	104	78
	288 (550)	575T	>3	319	341	343	334	334
	288 (550)	576T	>3	302	296	243	287	282
	288 (550)	577J	>3	226	321	331	266	287**
	302 (575)	568T	4	800	649	781	710	735
	302 (575)	569J	4	1226	996	816	709	937
	302 (575)	570J	4	847	1089	759	877	898**

* Direct calculation by method in Appendix D. Other values determined by multiplying 0.57 times the total breakdown voltage (sum of voltage readings at 15 each 2-mm station).
**Based on thickness measured at 2-mm station in each quadrant and average thickness at each 2-mm station.

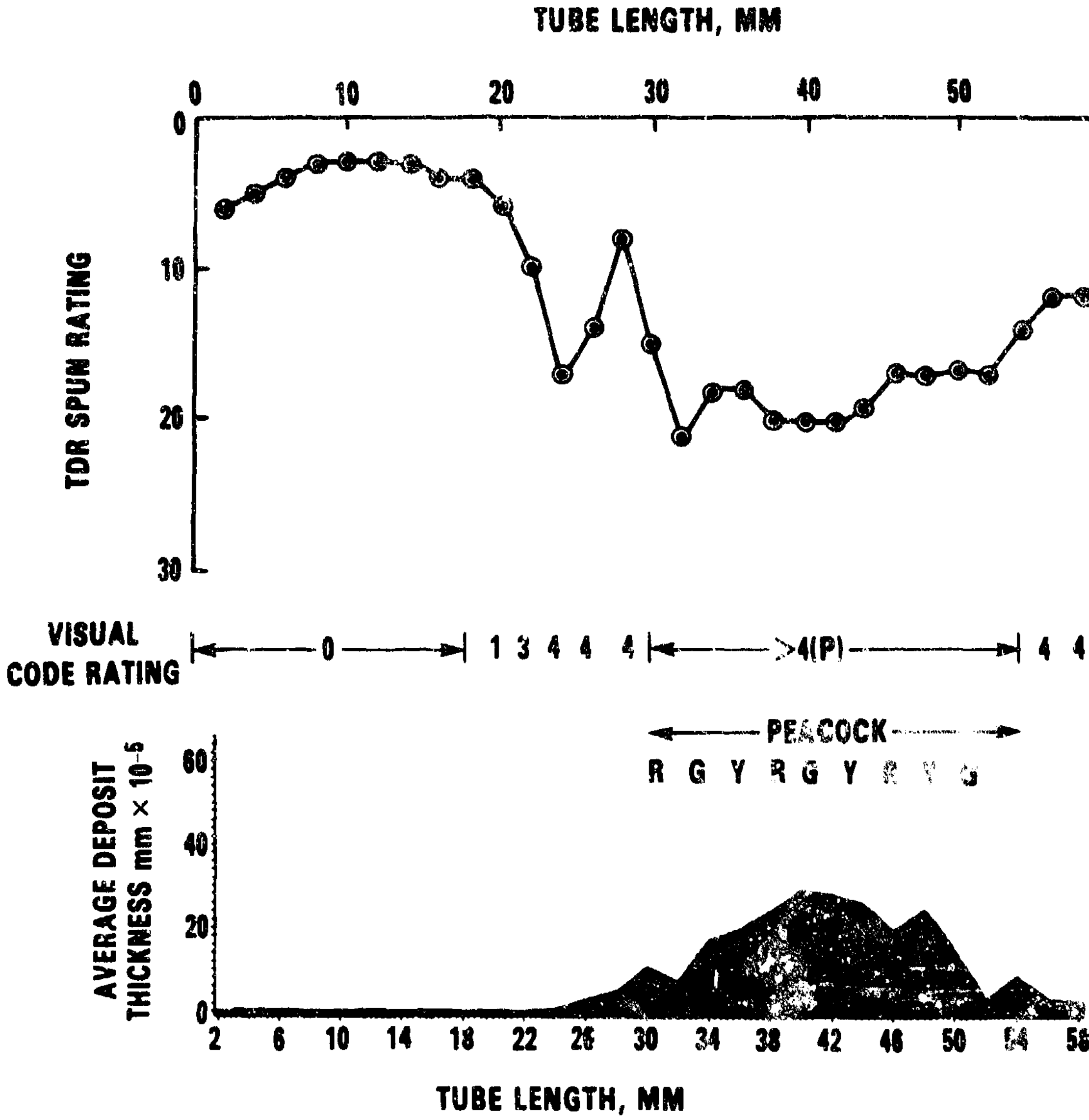


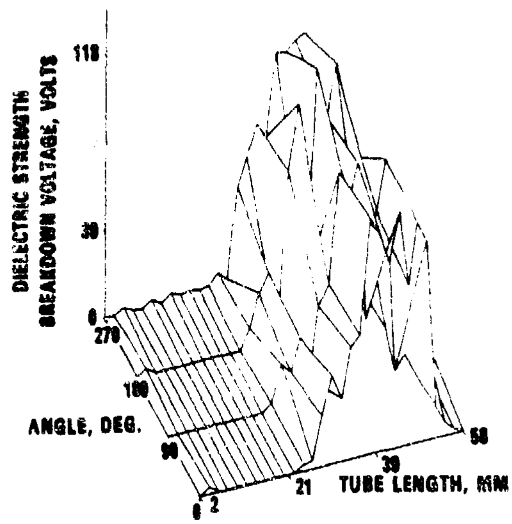
FIGURE 31. D 3241 TEST TUBE FOR 1% SULFUR: 218°C (425°F) (TUBE NUMBER 524T)

Using the calculated deposit volumes based on average dielectric breakdown voltage at each 2-mm station (from Appendix D), Figure 33 demonstrates the definition of JFTOT breakpoint temperature based on selected deposit volume limits of 50, 100, and 200 $cm^3 \times 10^{-7}$. Also shown for comparison in Figure 33 are the approximate breakpoint temperatures based on visual Code 3 inception temperature.

c. Visual Rating

Little can be said of the results obtained by visual rating except that the deposits formed for each fuel were, as expected, more severe as testing temperature was

(1% SULFUR FUEL, D3241 TEST TEMPERATURE OF 218°C, TEST TUBE NO. 524T)



AREA PLOT FOR TUBE DEPOSIT TEST 524T

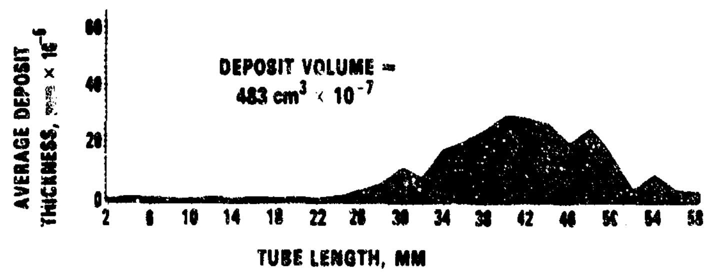


FIGURE 32. DIELECTRIC STRENGTH BY ANGLE BY TUBE LENGTH COMPARED TO DEPOSIT AREA PLOT

LEGEND	BREAKPOINT TEMPERATURE, °C			
	BASED ON DEPOSIT VOLUME			BASED ON
	200	100	50	CODE 3
○ 1% SULFUR FUEL	208	192	179	201
□ CAT 1-H	271	249	234	228
△ DIESEL CONTROL	287	279	276	284
▽ JET A-1	292	289	288	279

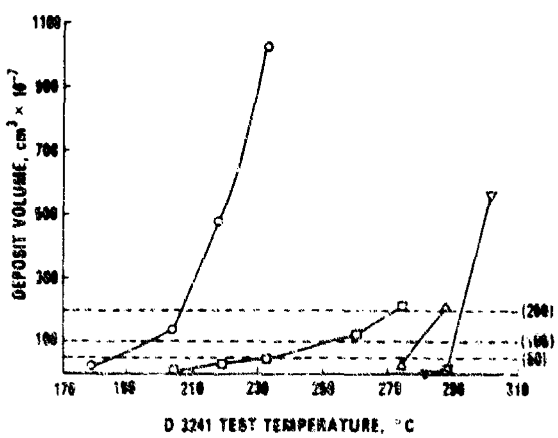


FIGURE 33. TEST TUBE DEPOSIT VOLUMES FOR FOUR FUELS AT VARIOUS D 3241 TEST TEMPERATURES

increased. This is illustrated in Figure 34 as a plot of visual rating versus test temperature for the four primary test fuels. The narrow dynamic range of the

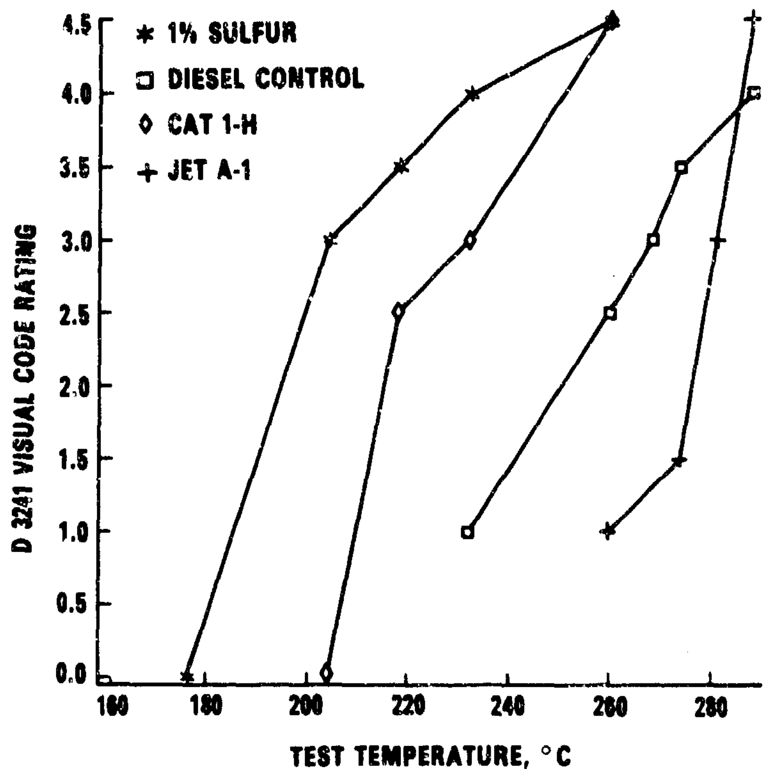


FIGURE 34. VISUAL RATING VERSUS TEST TEMPERATURE

visual technique and the inability to quantitate variations between the steps of the rating scale precluded attempts at establishing definitive correlations between visual rating and the other techniques. These same problems of range and resolution prevented the presentation of visual test data as an Arrhenius-type reaction rate plot. Another serious limitation of the visual rating approach was its inability to rate "peacock"-type deposits which are frequently encountered when testing diesel fuels.

d. <u>Thermal Deposit Rater</u>

Results obtained by Thermal Deposit Rating (TDR) for the four primary fuels are shown in Figure 35 as a plot of TDR rating units versus test temperature for each

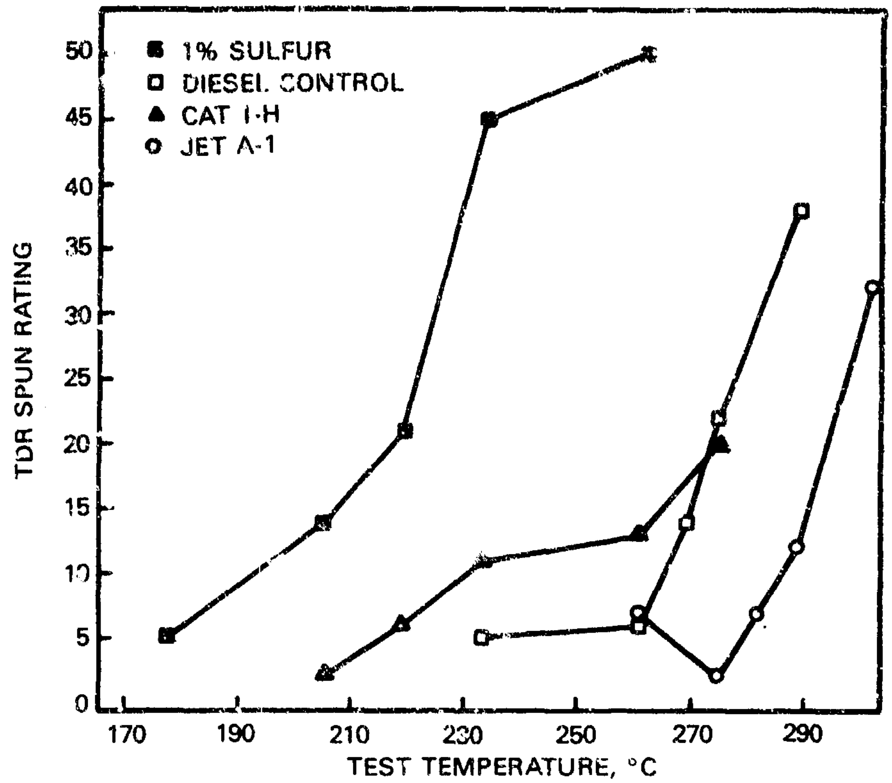


FIGURE 35. HIGHEST SPUN RATING (AVERAGE 3 TUBES) VERSUS TEST TEMPERATURE

of the fuels. In general, the deposit rating for each fuel became more severe as testing temperature was increased. An exception to this expected trend occurred with the Jet A-1 fuel. A TDR rating of 7 at 260°C (500°F) decreased to a 2 TDR rating at 274°C (525°F), then increased to 7 again at 281°C (538°F). Considerable scatter exists in both the visual rating and the TDR rating of the triplicate tests with Jet A-1 at those testing temperatures. The dielectric method showed no appreciable deposits on the Jet A-1 tubes until a temperature of 288°C (550°F) was reached.

The TDR rating scale is nonlinear with its greatest sensitivity in the 0- to 10 scale unit range. Sensitivity decreases considerably as higher value numbers are obtained.

e. Auger Spectrometer/Ion Milling

Selected locations on a limited number of tubes from the test matrix were analyzed using Auger spectrometer/ion milling as a means of determining deposit thickness. Elemental concentrations of carbon, oxygen, and aluminum were plotted against time, while ion milling was being performed on the deposit. The Auger spectrometer is sensitive only to elements present on the extreme surface of the material being analyzed, so any increase of detected aluminum was used as an indication that the fuel deposit had been milled through. The time required to mill away the deposit was recorded. Two different milling rates were evaluated. The first milling rate was approximately 50 microamps/cm^2. This speed proved to be unrealistically slow for thicker deposit analysis, so the rate was increased to 125 microamps/cm^2.

When Auger milling time was plotted against dielectric breakdown voltages for each location, a reasonable correlation for both milling rates was established for milling times of up to 50 minutes. As shown in Figure 36, the 50 microamp per

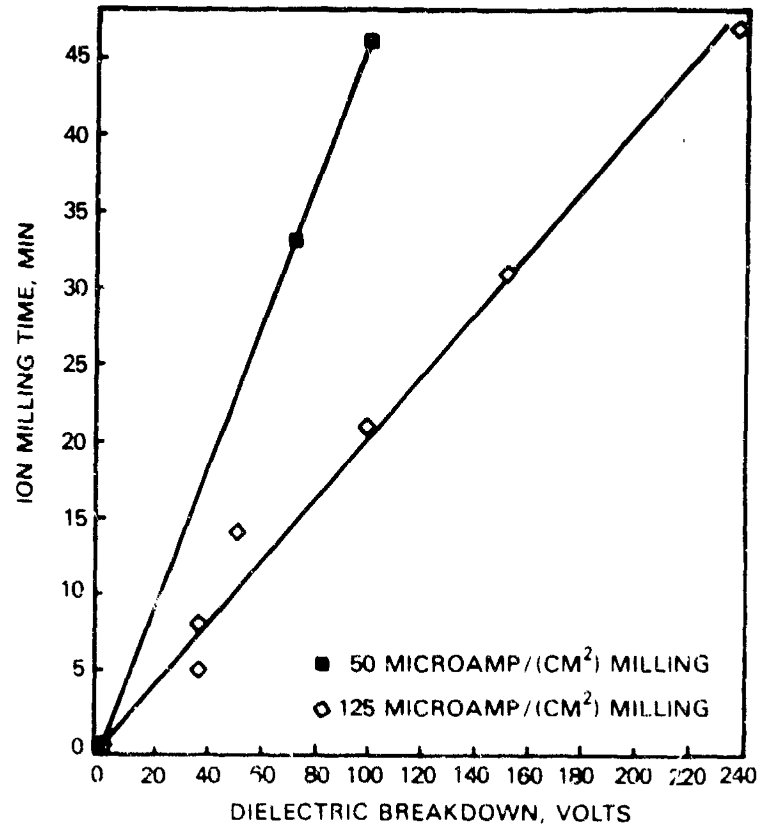


FIGURE 36. DIELECTRIC BREAKDOWN VOLTAGE VERSUS AUGER ION MILLING TIME

cm^2 rate indicates a linear removal rate, but insufficient data points were generated to confirm this linearity. The plot for 125-microamp per cm^2 milling rate shows good linearity for the six points on its plot. If the dielectric voltages are converted to thickness values based on 350 volts = 1 micrometer of thickness, the slope of the line for 125 microamps per cm^2 indicates a removal rate of 0.014 micrometer per minute of ion milling time. Two data points involving deposits which required over 2 hours to mill through are not presented in Figure 36. These two locations required considerably longer milling times than their dielectrically determined thickness would predict. This may indicate that the plotted line for the 125-microamp per cm^2 milling rate begins to deviate from linear response somewhere between 50 minutes and 120 minutes of milling time. More data points in this milling time range would be required to establish a definitive milling rate for these thicker deposits.

f. Comparison of Techniques

None of the rating techniques evaluated is a panacea suitable for universal rating of thermal oxidation deposits. Under certain conditions, each of the techniques gives an inaccurate evaluation. The conditions that cause erroneous readings seem, in most cases, to relate to the formation of "abnormal deposits" which are distinctively different from the normal varnish-like deposit in coloration, and are easily differentiated from normal deposits by an experienced rater. The peacock deposits which are commonly formed when testing diesel fuels appear to be normal deposits in nature. The peacock coloration is not a true color change in the deposit itself, instead appearing to be an effect of light passing through layers of deposit representing one-fourth wavelength multiples of the light's wavelength.

The visual rating approach, while suitable for go/no-go testing requirements based on prior experience of fuel performance at various rating levels, is unsuitable for research studies due to its narrow scale range, its subjective color matching, and its inability to evaluate peacock deposits. Visual rating is, however, an excellent approach for spotting the "abnormal" deposits which could cause errors in TDR or dielectric evaluations.

The TDR spun rating method is an improvement over the visual rating in several ways. It has a much broader scale range (0 to 50), is not subjective in nature, and produces similar readings for different operators. The major weaknesses in the TDR approach are that a thin dark deposit will be rated just as severely as a thicker but more transparent deposit. Variations in tube surface finish can affect tube reflectivity introducing error in the reflected light measurement, and the 0- to 50-scale of measuring units is nonlinear in response, with reduced sensitivity to change as the numbers increase in value. These weaknesses make quantitation and correlation of test results rather difficult.

The dielectric method shows considerable promise as a research tool for comparison of deposits. It is not as sensitive to very thin deposits as TDR, but shows tremendous potential for evaluation of deposits in the range of visual Code 3 and greater. The only way this method can produce significant errors is if the deposit has unusual electrical properties as compared to normal deposits. Most deposits with unusual electrical properties can be detected by comparing dielectric value to TDR rating. The fact that a deposit produces very low dielectric values but high TDR values is a strong indication that the deposit is not the normally encountered varnish-like deposits which function well as electrical insulators and should thus be classified as abnormal deposits. The major advantage of the dielectric method is its ability to equate breakdown voltages to approximate thickness and volumes.

The Auger spectrometer/ion milling approach to thickness measurement appears, from the limited data generated within this program, to have potential to evaluate deposit thickness. This approach deserves further evaluation as it may prove to be the best method available for measuring and quantifying the relatively thin deposits of visual Code 3 and less. The primary disadvantages to this approach is that it requires access to a very costly instrument that may be unavailable to most investigators, and the time required to check multiple locations by this approach can become excessive.

D. Kinetic Studies Utilizing Dielectric Method (Preliminary Application)

1. Background

Preliminary testing was performed to illustrate the potential research applications of the dielectric method to studies involving variables that can influence reaction

mechanisms or kinetics. These tests were designed to evaluate the effects of JFTOT tube alloy, test fuel flow rates, and additive blends on deposit formation.

Personnel from SwRI's Robotics and Automation Section of the Electronic Systems Division have designed and built a compact, portable prototype system to facilitate gathering of breakdown voltage data from JFTOT tubes. This system is known as the thermal stability Deposit Measuring Device, or DMD. In this system, JFTOT tubes are inserted into a holder and secured by a thumb screw. The holder has provisions for rotating the tube from 0 to 360 degrees. A linear translation stage holds a probe mechanism that can be positioned to an accuracy of 0.1 mm over a range of about 60 mm, the length of the JFTOT tube deposit region. Thus, the probe can be positioned accurately at any point on the surface of a deposit on the tube. A voltage ramp varying from 0 to 900V maximum is applied across a JFTOT sample from electrical connections on the tube holder and the probe. Three separate analog peak-voltage detector circuits monitor the voltage applied across the sample. The ranges of the peak detectors are 0 to 20V, 0 to 200V and 0 to 2000V. An "auto-ranging" control circuit selects the proper peak detector to monitor and displays the output of that detector on a digital voltage panel meter. At the point in time of dielectric breakdown of a deposit, the voltage across the sample decreases sharply, approaching a short circuit condition. The peak detector circuit, however, maintains the maximum voltage attained, which is the breakdown voltage. Presently, these data are manually recorded. A single push button is used to reset the system and initiate the next test. The DMD was used to generate all dielectric data in this section of the report. The results of stainless steel versus aluminum JFTOT tube tests are included in Appendix E.

2. Effects of JFTOT Tube Alloy

Table 30 is a summary of test results obtained when three of the fuels used in the test matrix of aluminum tubes were tested using stainless steel JFTOT tubes.

The Cat 1-H fuel, when tested with stainless steel tubes, produced an abnormal deposit with coloration ranging from white to blue or green tones. The fact that this unusual deposit was produced on each of the triplicate tests with stainless steel tubes is strong evidence that the alloy has affected the character of the

TABLE 30. COMPARISON OF VOLUME OF DEPOSIT, BASED ON DIELECTRIC STRENGTH BREAKDOWN VOLTAGE, ON STAINLESS STEEL HEATER TUBE AND ALUMINUM HEATER TUBE

Fuel Code	Temperature, °C (°F)	Test No.	Visual Code Rating	Volume of Deposit, $cm^3 \times 10^{-7}$				
				0°	90°	180°	270°	Average
Cat I-H (AL-13618-F)								
Stainless Steel Tube	232 (450)	1	4	53	45	37	46	46
	232 (450)	2	4	48	49	62	46	51
	232 (450)	3	4	36	34	37	51	40
Aluminum Tube	232 (450)	493J	3	36	20	59	25	35
	232 (450)	498T	3	44	35	40	40	41
	232 (450)	511J	3	30	40	71	88	58
Jet A-1 + Tetralin (AL-13633-T)								
Stainless Steel Tube	268 (515)	1	4	103	117	201	194	154
	268 (515)	2	4	421	345	115	257	285
	268 (515)	3	4	324	284	210	189	252
Aluminum Tube	268 (515)	547J	2	0	0	0	0	0
	268 (515)	548T	0	0	0	0	0	0
	268 (515)	551J	2	0	0	0	0	0
Jet A-1 + Tetralin + Thiophene (AL-13636 T)								
Stainless Steel Tube	281 (538)	1	>4	3060	3154	3213	2672	3025
	281 (538)	2	>4	3346	3301	3384	3617	3412
	281 (538)	3	>4	1998	2107	2487	2398	2306
Aluminum Tube	281 (538)	566J	3P	182	131	117	113	136
	281 (538)	567T	3P	176	143	194	308	205
	281 (538)	578T	3P	47	88	71	104	78

deposit since normal deposits were formed by this fuel with aluminum tubes. Unfortunately, the abnormal nature of this deposit made it impossible to definitively evaluate by any of the rating methods. The deposit appeared "thin" visually, but the colors could not be properly matched to the visual color chart. TDR indicated a higher scale reading when testing the stainless steel deposits, but it is unknown if this is an effect of thickness or coloration. Dielectric evaluation indicates, as shown in Table 30, that the deposits are nearly identical in volume for both the stainless and aluminum tubes. This comparison technique is also unsuitable in this case, since it is quite possible that the abnormal deposit on the stainless steel tubes may have considerably different electrical properties than the normal varnish-like deposit. While quantification of alloy effect could not properly be performed with this fuel, the abnormal nature of the stainless steel tube deposits does indicate that alloy effects are involved.

The Jet A-1 with tetralin fuel blend produced striking differences when tested with stainless steel tubes. At the 268°C test temperature, no detectable deposit was formed on the aluminum tubes. This was confirmed by all the evaluation techniques. When tested with stainless steel tubes, the fuel formed a deposit detected by all the methods. Dielectric method indicates the deposit volumes on the stainless steel tubes varied from 154 to 285 $cm^3 \times 10^{-7}$.

Jet A-1 with tetralin and thiophene produced a normal-appearing deposit on both the aluminum and stainless steel tubes. All techniques detected an increase in deposits on stainless steel tubes. Visual rating increased from Code 4 to > 4. The TDR rating increased from approximately 30 units to 50 units. In visual appearance, the stainless steel tube deposits were obviously a considerably thicker deposit than the aluminum tubes. However, neither optical rating method could show the degree of deposition differences since the stainless steel tube deposits were beyond the upper rating limits for these techniques.

The dielectric method was, however, able to easily resolve the magnitude of difference between the deposits. As shown in Table 30, the deposit volumes on the stainless steel tubes are from 10 to 20 times greater than the aluminum tube. This supports the visual observation that the stainless steel tube deposits appeared to be considerably thicker than the aluminum deposits.

Tests of the effects of stainless steel versus aluminum JFTOT tubes were also performed using Jet A-1, diesel control, and 1-percent sulfur fuels. These tests were run with single tubes rather than triplicate testing. These tests also showed a considerable increase in deposit volume formed when stainless steel tubes were used. This is illustrated in Table 31, which summarizes the deposit volumes detected by dielectric means.

TABLE 31. COMPARISON OF STAINLESS STEEL AND ALUMINUM JFTOT TUBES

		Aluminum		Stainless Steel	
Fuel Tested	D 3241, °C	Visual Code Rating	Deposit Volume, $cm^3 \times 10^{-7}$	Visual Code Rating	Deposit Volume, $cm^3 \times 10^{-7}$
Diesel Control	268	>4	71	>4	715
Jet A-1	281	>4	54	>4	1669
1% Sulfur Diesel	204	>4	25	>4	54

3. Effects of Additive and Flow Rate

To illustrate the potential of the dielectric method for evaluation of additive and flow rate effects, a small matrix of 10 aluminum tubes was tested. These tests compared the deposit formation of Cat 1-H fuel and Cat 1-H fuel with additive treatment (MIL-S-53021 (stabilizer only)), at several flow rates and total test times. The test results are summarized in Table 32, and data sheets are included in Appendix F. All 10 of the tests in this matrix were performed at 260°C (500°F). As shown in Table 32, flowing 450 mL of test fluid through the JFTOT tester at 4.5 mL/min for 100 minutes produced very little total deposit with neat or additive-treated fuel. This is probably due to the short residence time of the fuel at this flow rate.

TABLE 32. EFFECTS OF ADDITIVE AND FLOW RATE
(All Tests at 260°C (500°F)

Fuel Volumes and Flow Conditions	Cat 1-H Fuel Deposit Volume, $cm^3 \times 10^{-7}$	Cat 1-H Fuel With Additive: Deposit Volume, $cm^3 \times 10^{-7}$	Cat 1-H Fuel With Additive: Volume % of Additive Treated Deposit As Compared to Neat
450 mL Total, 4.5 mL/min, 100 min	91	95	100
450 mL Total, 3 mL/min, 150 min	3616	242	7
450 mL Total, 1.5 mL/min, 300 min	3938	1860	47
900 mL Total, 3 mL/min, 300 min	6794	841	12
900 mL Total, 1.5 mL/min, 600 min	5099	2951	58

When the flow rate was reduced to 3 mL/min for 150 minutes (the standard JFTOT flow rate), a drastic increase in deposit volume was noted for the neat fuel with 3616 $cm^3 \times 10^{-7}$ of deposit formation. The additive-treated fuel, under the same flow conditions, produced only 7 percent of the deposition volume produced by the neat fuel.

When flow rates were further reduced to 1.5 mL/min for 300 minutes, the deposit volume produced by the neat fuel was very close to the volume produced at 3 mL/min. The additive-treated fuel, however, did not perform as well at the 1.5-mL flow rate. While it still produced less deposit volume than the neat fuel (47 percent) at the 1.5 mL flow rate, the effectiveness was n t as great as was noted at 3-mL flow rate.

Tests were also performed with neat and additive-treated fuel using 900 mL of test fluids at both 3-mL/min and 1.5-mL/min flow rates. Table 32 illustrates that while the increased volumes of test fluid and longer testing times produced increased deposits for both the neat fuel and additive-treated fuel, the reduction of deposit volume with additive treatment was approximately the same percentage encountered on the tests involving 450 mL of fluid volume.

Since measurable deposits were formed on all of the 10 tubes of this matrix, it was decided to plot the number obtained by totaling the TDR ratings at each 2-mm distance along the tube against the total volume obtained for each tube by the dielectric method. This was done to determine if total of TDR ratings along a tube can be correlated to the deposit volume by the dielectric method. As Figure 37 illustrates, the correlation for these 10 tubes is quite good, which shows that total TDR rating may be usable for determination of deposit volume, at least within a limited range. This should be further evaluated in any future testing programs.

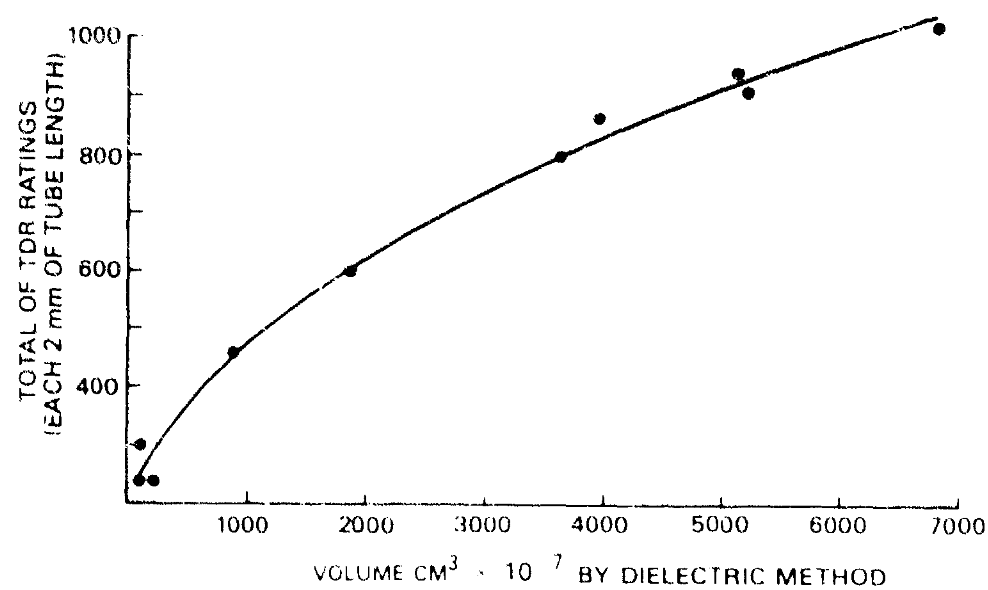


FIGURE 37. TOTAL OF TDR RATINGS VERSUS VOLUME BY DIELECTRIC METHOD

V. APPLICATION OF HOT LIQUID PROCESS SIMULATOR INSTRUMENTATION TO DIESEL FUEL THERMAL STABILITY

In the late 1960's, Alcor Inc. of San Antonio, TX designed a new method for testing jet fuel fouling tendencies. The Jet Fuel Thermal Oxidation Tester or JFTOT, became, and still is, a standard used worldwide.(10,16) Soon after the introduction of the JFTOT, several were purchased for high-temperature testing and research of petroleum liquids. Although this work was promising (17), it soon became apparent that the specific nature of the JFTOT test limited its usefulness for research. It was at this point that Alcor built a unit strictly for research, the Thermal Fouling Tester (TFT). The TFT used the same basic principle as the JFTOT, i.e., resistive heating of a metal tube in a tube-in-shell heat exchanger; however, the TFT eliminated the differential pressure measurement and added higher temperature/pressure capabilities. With time, further variants of the TFT were built: models with extended tube lengths, variable flow rate, heated systems, and some with all of these features. The ultimate variant was the research JFTOT or Thermal Oxidation Fouling Tester (TOFT). This unit had many of the features of the TFT's plus the addition of a high-pressure manometer. This unit was adopted for AFQP testing and evaluation at Belvoir F&L Research Facility in the Army's Mobility/Combat Fuels research program.

In 1982 (18) Alcor began design of a new research heat transfer system. The Hot Liquid Process Simulator (HLPS) system resulted from this effort. With the HLPS, a researcher has the JFTOT and TFT combined in one modular system that can be expanded or modified to fit any requirements.

A Hot Liquid Process Simulator (HLPS) purchased by Southwest Research Institute from Alcor Inc. in 1984 became operational in June 1985 (see Figure 38). One of the systems to which the HLPS can be configured is in the representation of a fuel injector system with the tube acting as the hot test surface. Before initiating this work, it was felt necessary to first verify that the HLPS could provide standard ASTM D 3241 type results. This would lend confidence to the data obtained where no direct comparison could be made.

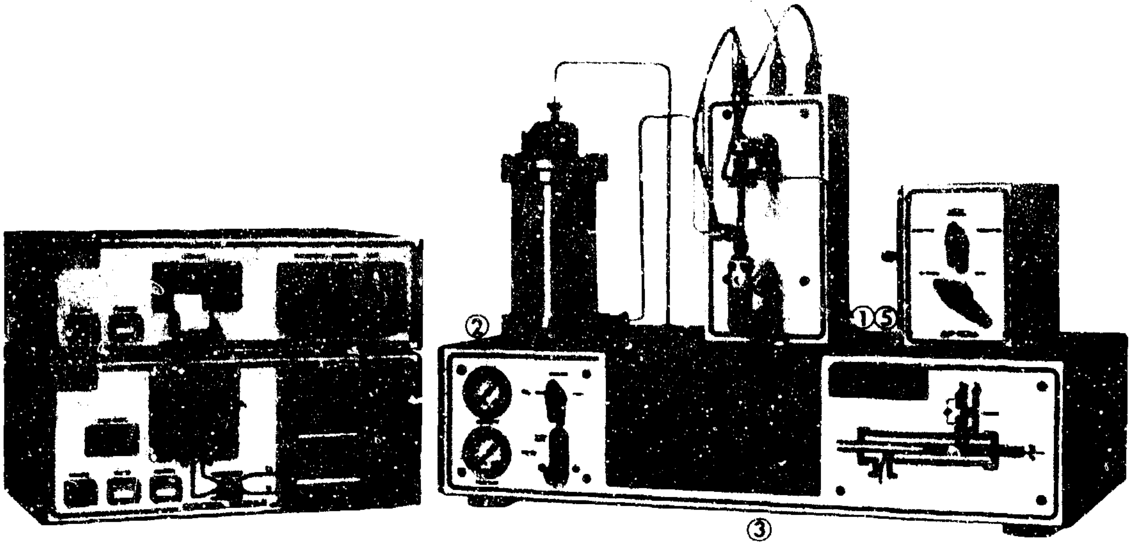


Photo Source: ALCOR

Modifications
1. New temperature (tube current) control board assembly
2. Line restrictor to limit pressure surges
3. Pump size reduced
4. New cooling bus bar
5. Alternate method to determine changes in heat output as a function of film thickness

FIGURE 38. ILLUSTRATION OF HOT LIQUID PROCESS SIMULATOR

After more than a year of testing which included a significant number of modifications and adjustments to the HLPS system, a final evaluation of the system was made.

Tube temperature profiles for JFTOT, TOFT, and HLPS equipment were obtained and compared to profiles listed in the ASTM D 3241 procedure. Three profiles using a JFTOT apparatus (including one in which the water flow was intentionally reversed) and one using a TOFT unit, each at a 224°C (435°F) set point were made.

The three JFTOT tube temperature profiles repeated themselves within 5° to 10°F; however, profiles between equipment differed by as much as 20° to 30°F. Variations between JFTOT and TOFT profiles and the D 3241 tables were up to

20°F using the 224°C (435°F) set point (Figure 39). Values of the experimental data varied from greater than to less than the tabulated values. The crossover was at about location 40 on the JFTOT thermocouple position scale.

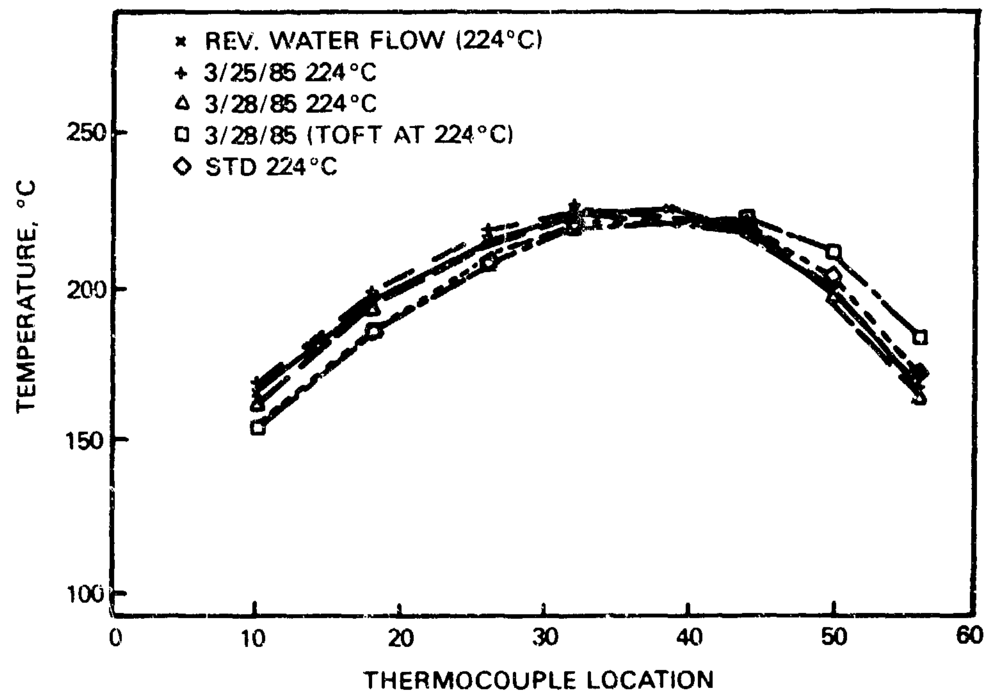


FIGURE 39. JFTOT DATA

Tube temperature profile data on the HLPS unit were taken at 218°C (425°F) and 260°C (500°F) after addition of a water-cooled member to the lower bus bar and a conversion from digital to analog tube temperature control. These HLPS tube profile data (Figure 40) were reasonably consistent with the standard profiles detailed in the D 3241 procedure. Maximum variation from the standard was less than 20°F for both sets of data.

Consistency was obtained with both visual tube ratings and the spun tube ratings obtained from HLPS, TOFT, and JFTOT systems. Based on these findings, it was concluded that the HLPS can duplicate the JFTOT apparatus in the ASTM D 3241 test method.

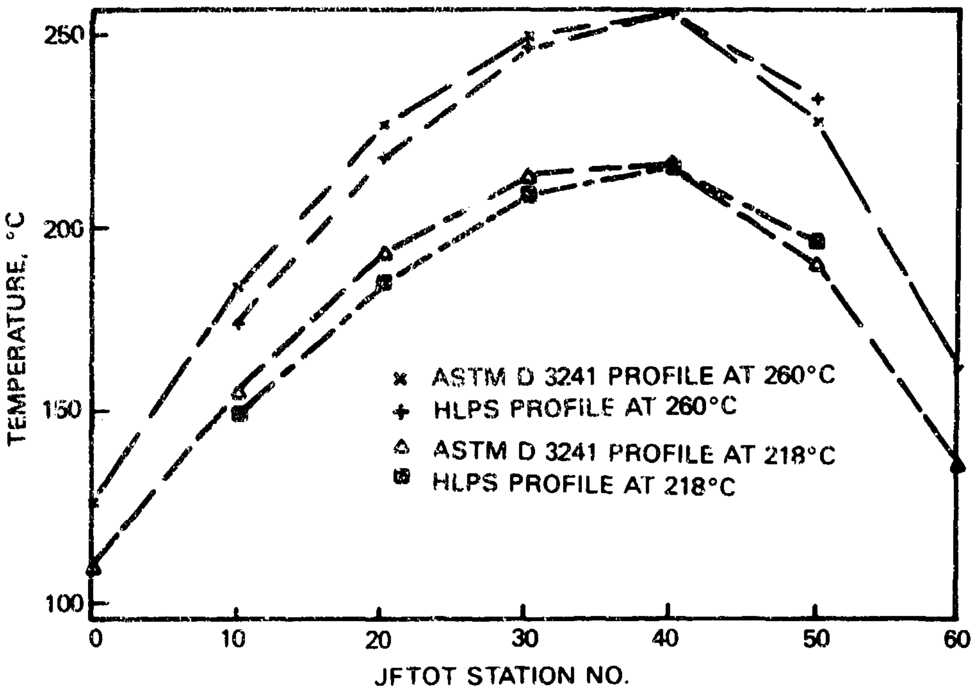


FIGURE 40. COMPARISON OF HLPS AND STANDARD VALUES

For the first time, the measurement of inlet and outlet fuel temperatures was examined closely. After 6 hours at 232°C (450°F) using Cat 1-H fuel, no perceptible temperature changes occurred other than apparently random oscillations of 1 to 2 degrees, even though a significant deposit had formed on the tube. In determining if this was a real result, the configuration of the apparatus was reviewed. Significant heat is conducted through the outer wall of the flow chamber so that ambient conditions could affect the results of the experiment. Also, location of the outlet temperature sensor is several millimeters downstream from the end of the heated tube. This could also reflect measurable heat loss since the fuel has to flow through right angle couplings. A method by which the power supplied to the tube can be measured is under consideration. This is potentially much more accurate in measuring the thermal effects of deposit buildup.

A review of tuning and electronic components of the HLPS with an Alcor representative provided the following information:

1. The gain and proportional bands (PB) are related in that the gain controls total power (current) available (via the SCR) to heat the tube while the PB indicates the percent of attenuated power being used. Thus, to obtain a higher PB reading, the gain must be reduced.

2. The gain control regulates available SCR triggering from 4 to 20 ma in the second of two control loops. Minor adjustments to the first loop may be obtained using a front panel control.

3. Location of the gain control is next to and either above or behind the bias control depending on whether the circuit board is vertically or horizontally mounted.

4. When lowering the gain control significantly, the PB should be reduced to less than 50 percent using the keypads. If the gain still needs to be reduced and the PB has gone over 90 percent, the keypad to reduce the PB. All changes should be made in the manual mode.

5. The bias control is adjusted so that a zero volt output will be obtained when "out 1" is a zero percent.

6. Normal settings are PB 80-90 percent, rate .01 (should be kept there), reset 4.5. The latter controls the number of times per minute control calculations are applied to adjust instrument conditions.

7. Calibration mode of the control module (obtained by pressing the upper right and lower left keypads simultaneously) will reset the EROM (working memory) to the same conditions prescribed by the base memory.

8. Data output units may be changed, e.g., from ^{o}F to ^{o}C by first pressing simultaneously the upper left and upper and lower right keypads of the control module. Press the upper left keypad until the parameters to be changed appear on the LED screen, then press the forward backward keypads until the appropriate unit appears (C,F, etc.). Exit to the

tuning mode by pressing the lower left keypad. Remember that numerical parameters must also be changed (e.g., upper limit 751°F must be changed to 400°C).

9. The thermocouple (T_{in}, T_{out}) parameters may also be changed (°C to °F) by removing the two face plates, changing the switch location underneath and reversing the plates before replacing them.

The effect of filter screen size on the ΔP values during JFTOT analysis was studied for Cat 1-H. Filters having nominal pore sizes of 10 and 5 µm were employed (standard ≈ 17 µm). Temperatures between 400° and 500°F (204° and 260°C) (for 10-µm filter) and 460° to 500°F (238° to 260°C) (for 5-µm filter) were used for five determinations each. The 10-µm filter showed significant ΔP at 480°F (249°C) only. The 5-µm filter yielded an excellent family of curves as shown in Figure 41. It is planned to continue experimentation to determine potential correlation of injector fouling tendencies with HLPS system tests employing D 3241 JFTOT test tubes, new rating methods, smaller pore-size screens (probably 5-10 µm), and fuel effluent rating (evaluation). In August 1985, HLPS operating manuals were printed.(18)

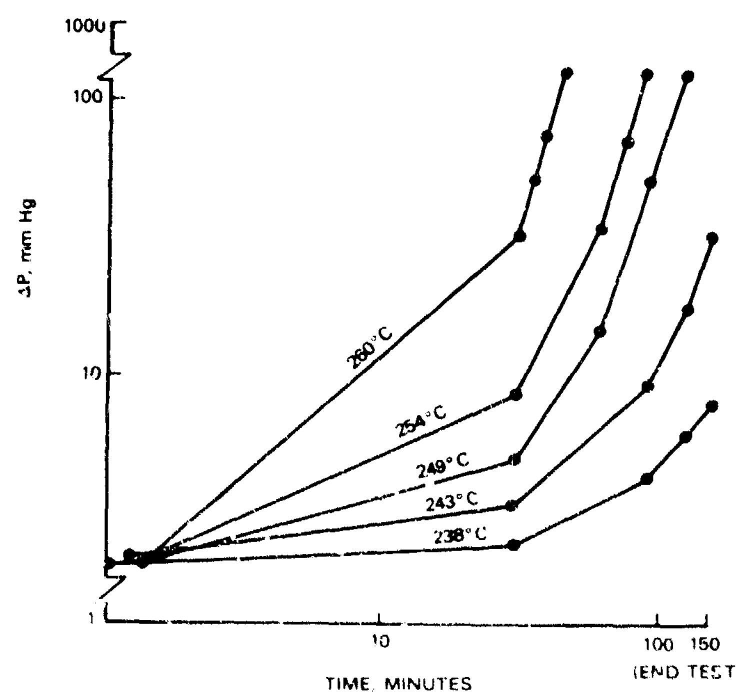


FIGURE 41. JFTOT ANALYSIS USING 5-MICROMETER TEST FILTERS IN CAT 1-H FUEL AT VARIOUS TEMPERATURES

VI. SUMMARY AND CONCLUSIONS

Experience ·ˑ ˉ ᶠᵔr with the Injector Fouling Bench Test (IFBT) using the CLR-D injectors and the DD 6V-53T injectors suggest that this is a viable approach to evaluate the deposit-forming tendencies of diesel fuels at elevated temperatures. The CLR-D hot engine test injector evaluations are difficult to reproduce on the IFBT due to combustion products' (including lubricants) contribution to injector tip/hole deposits. The injector tip hole plugging (fouling) in the engine tests (and IFBT) is a very random event which is difficult to repeat. Deposition on the injector pintle and in the holes of the injector body tip should receive the major evaluation emphasis as a function of injector fouling.

Fuel thermal instability products contributing to injector (internal and external) tip deposits are complicated by both fuel combustion and lubricant combustion phenomena. These "carbon residue" evaluations which contribute to injector and nozzle fouling would be better evaluated in microburner residue tests.

Visual rating methods for both IFBT and JFTOT tests lack sufficient quantitation and dynamic range to be very useful in evaluating the thermal stability of diesel fuels. Air flow techniques for measuring injector hole deposition are being adopted for further evaluation in future IFBT tests. Both TDR Spun and dielectric strength breakdown voltage provide a better quantitative measure of pintle deposits and JFTOT test tube deposits.

VII. RECOMMENDATIONS

Effort in this program in the near term should be focused on an expanded data matrix which would include very unstable fuels (including fluid catalytic cracked--light cycle oil) as well as the high-sulfur referee and Cat 1-H engine reference fuels. Temperature severity in IFBT tests must cover a sufficient range and duration for correlating with JFTOT-type tests. Engine testing, if done at all, should utilize an air-cooled engine capable of operating over a range of injector temperatures, both above and below that of the CLR-D hot engine test injector temperature range. Test fuel flow regimes, test surface metallurgy, and fuel additives should be important considerations in IFBT/JFTOT-type test correlations leading to the recommendation for fuel specification test and test limit definition.

In the long term, both bench test and modified JFTOT-type testing need to be expanded from compression-ignition engine injector considerations to include the ground turbine nozzle (in AGT-1500 engines) which utilize diesel fuels.

Limitation of the dielectric strength breakdown voltage technique for quantitating high-temperature deposit needs to be explored and defined.

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16. ASTM D 3241-82, "Test Method for Thermal Oxidation Stability of Aviation Turbine Fuels" (JFTOT Procedure), American Society for Testing and Materials, Current Editing Approved 27 August 1982, Published October 1982, Originally Published as D 3241-73T.

17. JFTOT Evaluation Panel, "Research Technique for Thermal Stability by Modified Jet Fuel Thermal Oxidation Test (JFTOT)," CRC Project No. CA-43-67, October 1977, Coordinating Research Council, Inc., New York, NY.

18. "HLPS I," Operation Manual, Alcor, Inc., March 1985.

APPENDIX A

CLR-D HOT TEST

CLR-D HOT TEST

1.0 Description

The CLR-D engine hot test was initiated to study lubrication mechanisms in adiabatic or low heat rejection engines. The inavailability of an adiabatic test engine resulted in the modification of a CLR-D engine to run uncooled. Table A-1 describes the CLR-D engine:

TABLE A-1. CLR-D OIL TEST ENGINE

Configuration	Direct Injection
Bore, cm (in)	9.65 (3.80)
Stroke, cm (in)	9.53 (3.75)
Displacement, cm^3 (in^3)	696.5 (42.5)
Compression ratio	14.33:1
Valve Timing (IN)	5^{o} BTC to 38^{o} ABC
(EX)	55^{o} BBC to 20^{o} ATC
Fuel injection system	Bosch APE
Barrel and plunger	6 mm
Injector	4-hole

The water jacket around the cylinder was left empty, and the water passages to the cylinder head were plugged. The cylinder head was cooled with ethylene glycol to keep the exhaust valve from burning. The cylinder liner was instrumented with 12 thermocouples, which ranged from top center of upper ring travel to bottom center of upper ring travel, at four positions 90 degrees circumferentially around the liner. Two of the positions included the thrust and antithrust sides. The air-fuel ratio was used to control the cylinder liner temperatures; however, this method proved inadequate due to the thermal lag of the system. A machined aluminum block was fitted with rod heaters and slipped around the cylinder liner.

A temperature controller was then used to control the cylinder liner temperature at the net point.

2.0 Preparation for the Test

The injection system is thoroughly examined to insure proper injector performance. The injector tip is rated clean with a TDR spun rating for baseline data. The injector is assembled and the pop-off pressure is set at 2500 psi, and the spray pattern is examined for proper atomization. The engine is assembled and the instrumentation calibrated. A positive displacement m ter is attached to the crankcase to monitor blowby, to determine the level of ring sticking.

3.0 Test Procedure

Table A-2 lists the test conditions for the CLR-D hot test:

TABLE A-2. TEST CONDITIONS

Test hours	40
Speed, rpm	2000
A/F ratio	30:1
Fuel flow, lbs/hr	3:0
Head temp, °C (°F)	154 (310)
Liner temp, °C (°F), average	334 (633)
Oil temp, °C (°F), galley	132 (270)

The test is run for 40 hours or until poor injector performance is indicated by increase in fuel consumption, loss of power, and increase in exhaust temperature. The engine is operated 7 hours a day, with a half hour warm-up and cool down. Lubricant level is monitored closely due to high lubricant consumption.

CLR–D / BOSCH INJECTOR
INSPECTION WORKSHEET

Date ____________ test no. ________ Test hours ________ Inspector ____________________

Fuel AL no. ____

Test	Typ./Ref.	Before	After
Injection pressure psi	2500		
Leakdown dP;15 sec.	report		
Spray Pattern	report		
Air flow cc/min.	report		

Tip Demerit Rating					
Non–Rubbing			Rubbing		
2			2		
3			3		
4			4		
5			5		
6			6		
7			7		
8			8		
9			9		
total			total		

TDR spun rating

station	before	after

Dielectric Breakdown

station	0	90	180	270

APPENDIX B

INJECTOR FOULING BENCH TEST METHODOLOGY FOR DIESEL FUEL THERMAL STABILITY

INJECTOR FOULING BENCH TEST METHODOLOGY FOR DIESEL FUEL THERMAL STABILITY

1.0 Scope

1.1 This methodology is being developed for evaluating the thermal oxidative deposition/sticking and/or fouling tendencies (under accelerated test conditions) of diesel injector.

1.2 This methodology will be used to determine the tendency of diesel fuel to cause sticking and/or fouling of injector parts in service operation.

2.0 **Apparatus**

2.1 **References**

2.1.1 **CLR-D Engine Manual**

2.1.2 **Detroit Diesel Series 53 Service Manual**

2.1.3 **Cummins P-T Injector System Manual**

2.1.4 **ISO 4010-1977 (E)**

2.2 **Injector Systems**

2.2.1 The injector systems used for IFBT evaluations represent the three most common injection systems used in diesel engines. The three IFBT apparatus were developed to examine the sensitivity of each unique injection system to fuel thermal stability.

2.2.1.1 The CLR-D IFBT apparatus represents a jerk pump-line-nozzle type of injection system. The jerk pump meters and pressurizes the fuel, which is carried to a remote nozzle by a high pressure line. All fuel recirculation occurs in the jerk pump and the bypassed fuel does not see high injector temperatures.

The IFBT apparatus was designed to simulate the injector pintle deposition of the CLR-D hot test engine. The apparatus is shown in Figure B-1. Thermal mapping of the pintle in the CLR-D engine determined the temperatures at which the injector is controlled.

2.2.1.2 The IFBT Detroit Diesel (DD) apparatus was developed to determine the injector deposition tendencies of the DD unit injector. The unit injector contains the metering/pressurizing assembly and nozzle in a single unit; thus the bypassed fuel is exposed to high injector temperatures. The interest in developing the DD rig spawned from the high fuel return rates of the unit injector in which the fuel is used to cool the injector in the cylinder head. The high recycle rate and the additional thermal stressing of the fuel are considered important factors governing the pintle deposition with the DD rig. Figure B-2 is a schematic of the Detroit Diesel test apparatus.

2.2.1.3 The IFBT Cummins apparatus was developed to examine the relative deposition tendencies of the Cummins PT-fuel injection system. The PT-fuel system uses a low pressure/high volume pump to supply fuel to the injectors at a constant pressure dependent on load. All metering occurs through an orifice in the injector. When the injector plunger is lifted off its seat, all remaining unmetered fuel is recirculated. The bypassed fuel is used to cool the injector, where it is exposed to high temperatures. Figure B-3 depicts the Cummins IFBT apparatus.

2.3 Preparation for Test

2.3.1 Prior to the test, the injectors for the respective bench test rigs are examined, based on the procedures outlined in their respective manuals. Additional tests include a nozzle airflow check and a TDR spun rating for baseline data of a clean pintle/plunger. The test undergoes a battery of tests listed in Table B-1.

TABLE B-1. FUEL TESTS

JFTOT Breakpoint
ASTM D 2276
ASTM D 2274

2.4 Test Procedures

2.4.1 For each of the three IFBT rigs, 20 gallons of the test fuel is procured. The injector rigs are operated at their respective conditions described in Table B-2.

TABLE B-2. IFBT OPERATING CONDITIONS

Condition	Bosch APE CLR-D	Detroit Diesel	Cummins
Test hours	40	40	40
Speed, rpm	1000	1000	1000
Fuel flow, gal/hr	0.5	0.5	0.5
Fuel pressure, psi	---	---	140
Fuel spray temp, ^{o}C (^{o}F)	288 (550)	204 (400)	204 (400)

After-test performance evaluations include the evaluations described in the respective injector references, plus the air flow test for the determination of nozzle hole plugging. The air flow evaluation is a modification of the ISO 4010-1977 (E) standard.

Also, following the completion of the test, the pintle/plungers are rated for deposition by the methods listed in Table B-3 and compared to their respective before-test measurements. Results are then listed in the respective work sheets (Figures B-4 through B-6).

TABLE B-3. IFBT DEPOSITION RATINGS

Visual CRC lacquer demerit scale
TDR spun rating
Dielectric breakdown
JFTOT visual rating scale

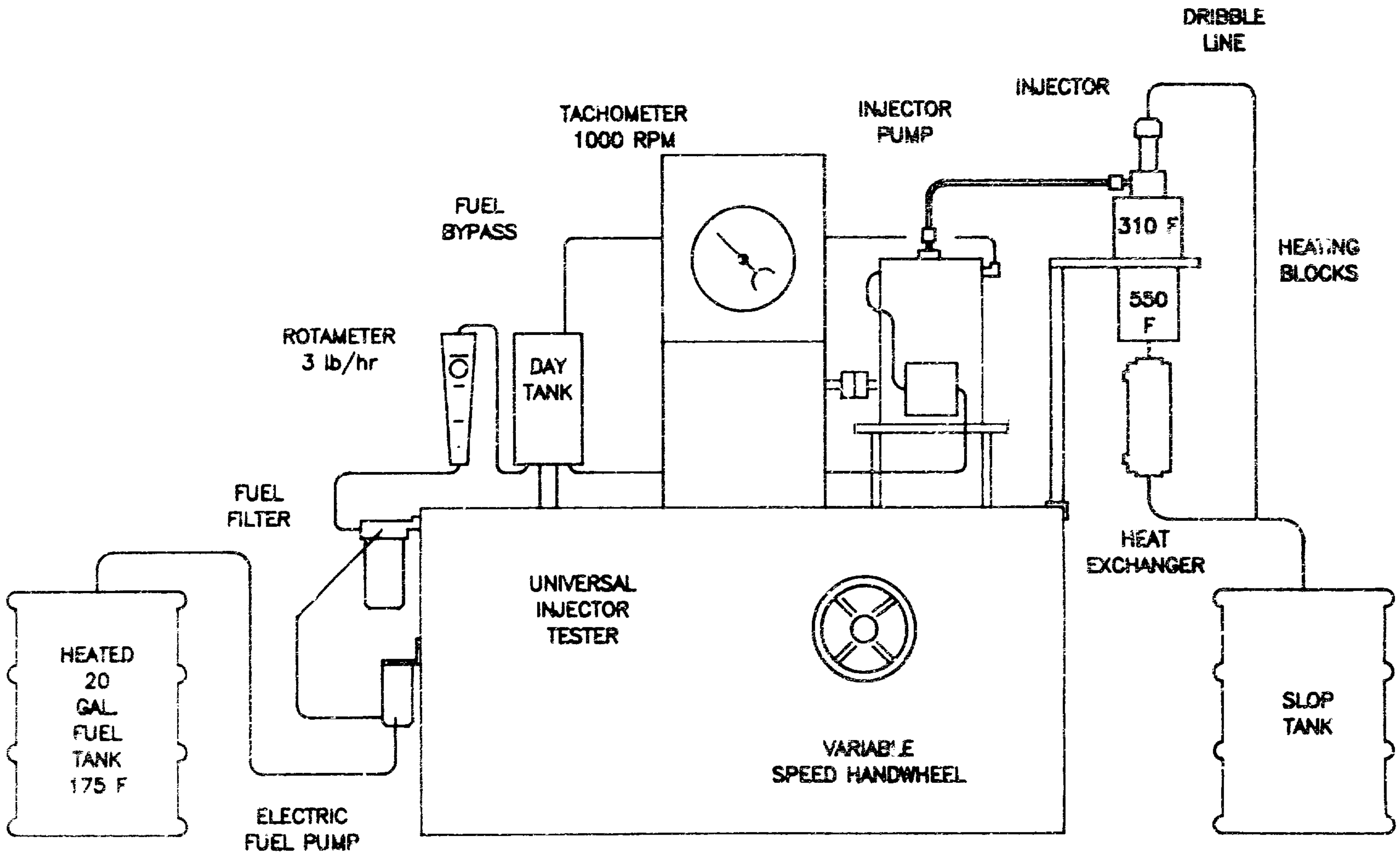


FIGURE B-1. CLR-D INJECTOR FOULING BENCH TEST APPARATUS

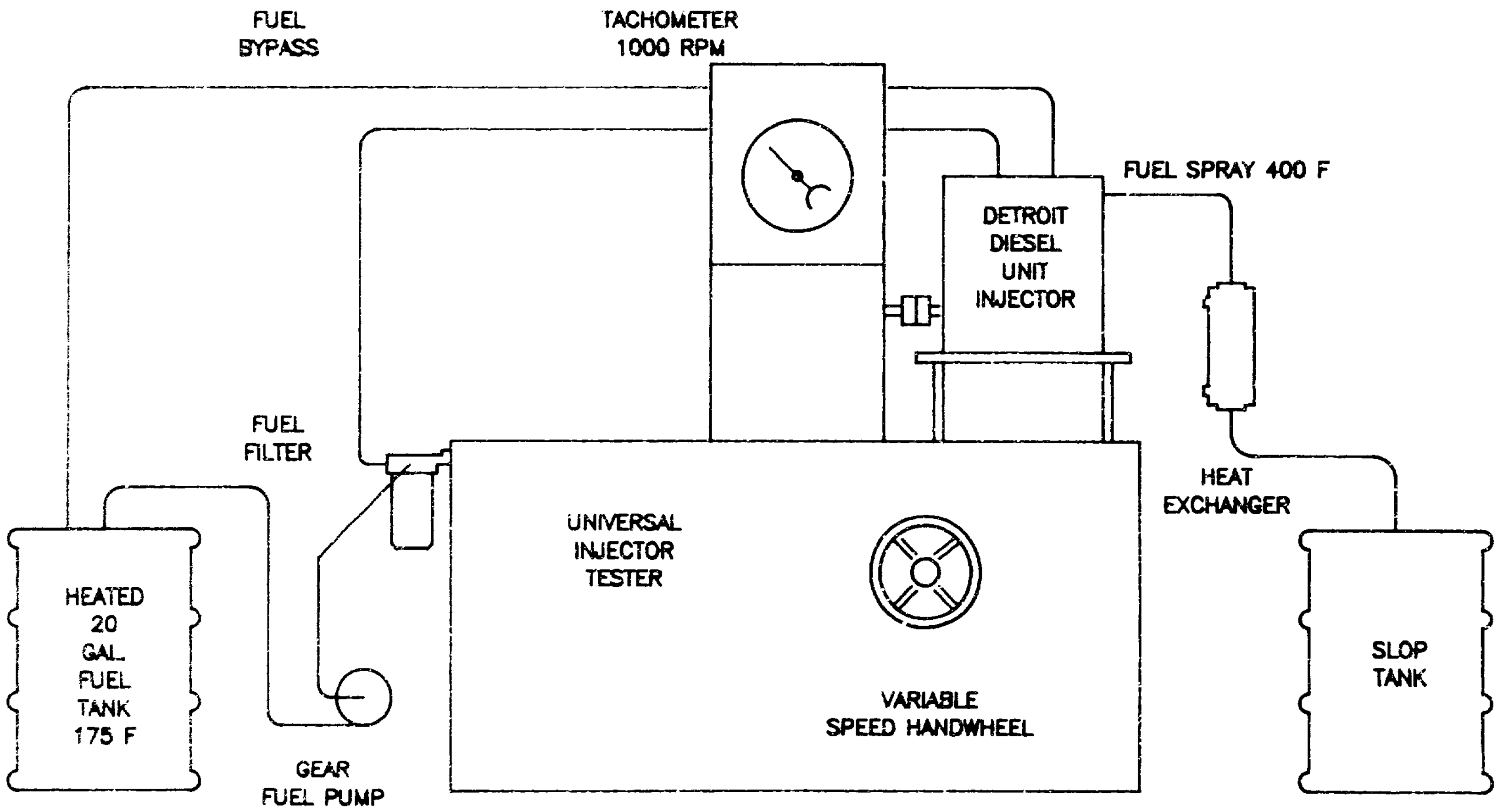


FIGURE B-2. DETROIT DIESEL INJECTOR FOULING BENCH TEST APPARATUS

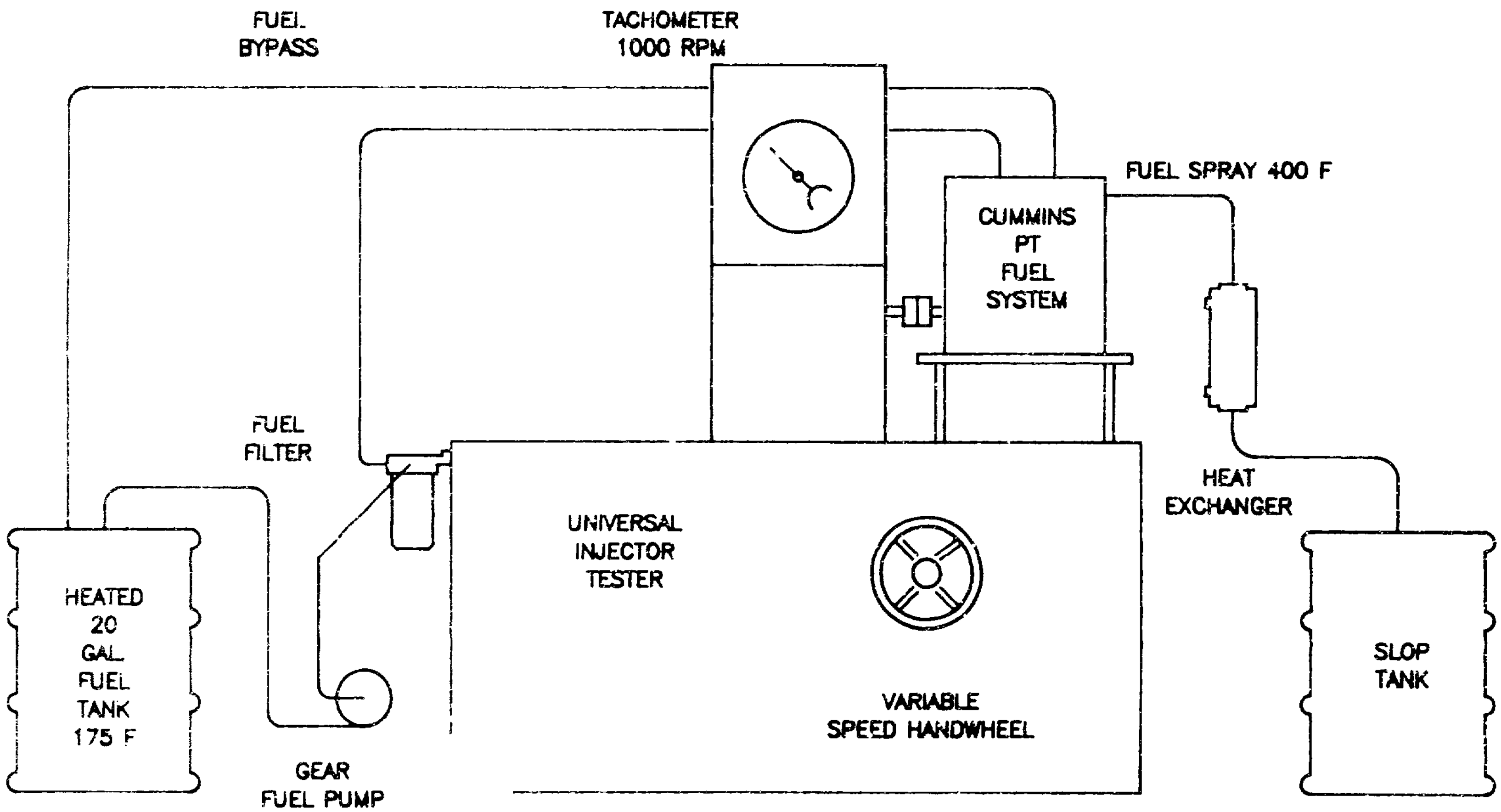


FIGURE B-3. CUMMINS INJECTOR FOULING BENCH TEST APPARATUS

FIGURE B-4

CUMMINS PT–SYSTEM INJECTOR
IFBT INSPECTION WORKSHEET

Date ________ IFBT test no. ______ Test hours ______ Inspector ____________

Fuel AL no. ____

Test	Typ./Ref.	Before	After
Spray Pattern	report		
Leakdown dP;15 sec.	report		
Air flow cc/min.	report		

Tip Demerit Rating					
Non–Rubbing			Rubbing		
2			2		
3			3		
4			4		
5			5		
6			6		
7			7		
8			8		
9			9		
total			total		

TDR spun rating

station	before	after

Dielectric Breakdown

station	0	90	180	270

FIGURE B-5

CLR–D / BOSCH INJECTOR
IFBT INSPECTION WORKSHEET

Date ______________ IFBT test no. __________ Test hours __________ Inspector ______________________

Fuel AL no. ____

Test	Typ./Ref.	Before	After
Injection pressure psi	2500		
Leakdown dP;15 sec.	report		
Spray Pattern	report		
Air flow cc/min.	report		

Tip Demerit Rating					
Non–Rubbing			Rubbing		
2			2		
3			3		
4			4		
5			5		
6			6		
7			7		
8			8		
9			9		
total			total		

TDR spun rating

station	before	after

Dielectric Breakdown

station	0	90	180	270

FIGURE B-6

DETROIT DIESEL N70 UNIT INJECTOR
IFBT INSPECTION WORKSHEET

Date ________ IFBT test no. ______ Test hours ______ Inspector __________

Fuel AL no. ____

Test	Typ./Ref.	Before	After
Pressure Reference Value	135		
Leakdown dP;15 sec.	0		
Fuel flow ml/1000 strokes	60–75		
Air flow cc/min.	report		

Tip Demerit Rating					
Non–Rubbing			Rubbing		
2			2		
3			3		
4			4		
5			5		
6			6		
7			7		
8			8		
9			9		
total			total		

TDR spun rating

station	before	after

Dielectric Breakdown

station	0	90	180	270

APPENDIX C

PRIMARY MATRIX TUBE DEPOSIT DATA

1% SULFUR REFEREE DIESEL AL-13619-F AT 177°C (350°F)—TEST 513T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	4	0				
04	0	0	0	0	0	2	0				
06	0	0	0	0	0	2	0				
08	2.8	0	0	3.0	1.5	1	0				
10	0	0	1.0	0	0.3	1	0				
12	0	0	0	0	0	1	0				
14	0	0	0	0	0	0	0				
16	0	0	0	0	0	1	0				
18	2.3	0	0	1.8	1.0	1	0				
20	1.8	1.7	1.9	2.1	1.9	1	0				
22	0	0	0	1.9	0.5	0	0				
24	1.5	0	0	2.3	1.0	1	0				
26	0	1.9	3.0	0	1.2	1	0				
28	0	2.9	0	0	0.7	1	0				
30	0	0	0	4.3	1.1	1	0				
32	0	0	0	0	0	1	0				
34	0	4.5	0	2.8	1.8	1	0				
36	0	4.7	6.8	2.2	3.4	1	0				
38	0	0	2.5	0	0.6	2	0				
40	6.7	0	1.4	0	2.0	2	0				
42	5.2	1.8	3.5	5.2	3.9	2	0				
44	2.4	0	3.7	1.9	2.0	2	0				
46	4.2	0	2.4	3.5	2.5	2	0				
48	0	0	1.8	3.3	1.3	2	0				
50	0	1.1	0	4.3	1.4	2	0				
52	2.4	0	2.4	2.5	1.8	3	0				
54	2.0	0	1.3	2.4	1.4	3	0				
56	0	0	0	0	0	4	0				
58	0	0	0	0	0	8	0				
TOTAL	31.5	18.6	31.7	45.5	31.5						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 2 at 150 min
Preheater Deposit Code: 0
TDR Spun Deposit Rating: 2 at 46

1% SULFUR REFEREE DIESEL AL-13619-F AT 177°C (350°F)—TEST 515T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	2	0				
04	0	0	0	0	0	1	0				
06	0	0	0	0	0	1	0				
08	0	0	0	0	0	0	0				
10	0	0	0	0	0	1	0				
12	0	0	0	0	0	1	0				
14	0	0	0	0	0	0	0				
16	0	0	0	0	0	0	0				
18	0	0	0	0	0	0	0				
20	0	0	0	0	0	0	0				
22	0	0	0	0	0	0	0				
24	0	0	0	0	0	0	0				
26	0	0	0	0	0	1	0				
28	0	0	0	0	0	1	0				
30	0	0	0	0	0	1	0				
32	0	0	0	0	0	1	0				
34	0	0	0	0	0	1	0				
36	0	0	0	0	0	2	0				
38	0	0	0	0	0	2	0				
40	0	0	0	0	0	2	0				
42	0	0	0	0	0	2	0				
44	0	0	0	0	0	2	0				
46	0	0	0	0	0	2	0				
48	0	0	0	0	0	2	0				
50	0	0	0	0	0	2	0				
52	0	0	0	0	0	2	0				
54	0	0	0	0	0	2	0				
56	0	0	0	0	0	2	0				
58	0	0	0	0	0	2	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 2 at 150 min
Preheater Deposit Code: 0
TDR Spun Deposit Rating: 2 at 48

1% SULFUR REFEREE DIESEL AL-13619-F AT 177°C (350°F)—TEST 5213*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	13	0				
04	0	0	0	0	0	8	0				
06	0	0	3.4	0	0.9	6	0				
08	0	0	3.9	0	1.0	7	0				
10	0	0	0	2.8	0.7	4	0				
12	0	0	0	3.9	1.0	4	0				
14	0	0	3.2	3.1	1.6	6	0				
16	0	0	3.0	2.3	1.3	4	0				
18	0	0	3.9	0	1.0	5	0				
20	0	0	1.6	0	0.4	3	0				
22	3.6	1.0	1.9	0	1.6	3	0				
24	0	0	2.2	0	0.6	3	0				
26	0	3.0	1.9	0	1.2	4	0				
28	0	0	0	1.8	0.5	4	0				
30	0	1.6	3.4	0	1.8	4	0				
32	2.9	2.8	0	2.1	2.0	4	0				
34	1.1	0	0	0	0.3	5	0	0.0033 μm Auger			
36	0	3.2	1.5	2.3	1.8	6	0				
38	2.4	0	3.0	3.1	2.1	6	0				
40	0	0	6.9	.4	1.8	7	0	0.0033 μm Auger			
42	0	0	3.5	0	0.9	8	0				
44	0	2.3	1.6	2.3	1.6	9	0				
46	3.2	[illegible]	7.9	3.8	4.7	9	0	0.007 μm Auger			
48	0	0	4.6	1.7	1.6	10	0				
50	0	4.4	3.4	1.3	2.1	9	0				
52	0	[illegible]	0	3.0	1.4	8	0				
54	0	0	0	3.7	0.9	9	0				
56	0	1.4	0	2.1	0.9	9	0				
58	0	0	0	0	0	10	0				
TOTAL	13.2	28.2	60.8	41.7	35.9						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 2 at 150 min
Preheater Deposit Code: 0
TDR Spun Deposit Rating: 13 at 48

1% SULFUR REFEREE DIESEL AL-13619-F AT 204°C (400°F)—TEST 5033*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	[illegible]	[illegible]	0	0	[illegible]	[illegible]	0				
04	[illegible]	[illegible]	0	0	[illegible]	2	0				
06	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
08	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	[illegible]				
22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12	[illegible]				
28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
32	[illegible]	[illegible]	[illegible]	[illegible]	21.0	[illegible]	[illegible]				
34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6	[illegible] (P)	[illegible] Auger			
36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] (P)				
40	[illegible]	[illegible]	28.0	[illegible]	[illegible]	[illegible]	[illegible] (P)		[illegible]	[illegible]	
42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12	[illegible]	[illegible] Auger		[illegible]	
44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] Auger	[illegible]		
48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
56	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20	[illegible]				
TOTAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 2 at 150 min
Preheater Deposit Code: 3P
TDR Spun Deposit Rating: 13 at [illegible]

1% SULFUR REFEREE DIESEL AL-13619-F AT 204°C (400°F)—TEST 5123*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	3	0				
04	0	0	0	0	0	1	0				
06	0	0	0	0	0	1	0				
08	0	0	0	0	0	1	0				
10	0	0	0	0	0	0	0				
12	0	0	0	0	0	0	0				
14	0	0	0	0	0	0	0				
16	0	0	0	0	0	1	0				
18	0	0	0	0	0	0	0				
20	0	0	0	0	0	1	0				
22	0	0	0	0	0	1	0				
24	0	0	0	0	0	3	0				
26	0	0	0	0	0	6	2				
28	0	0	0	5.0	1.3	12	3				
30	36.0	3.0	4.0	8.0	12.8	14	4				
32	40.6	[illegible]	2.0	4.0	17.7	8	4				
34	10.0	34.2	2.7	3.0	12.5	5	4				
36	6.4	43.2	1.8	2.1	13.4	9	>4 (P)				
38	2.0	30.0	34.8	45.9	28.2	16	>4 (P)				
40	37.1	7.0	45.9	50.8	35.2	15	>4 (P)				
42	41.5	26.3	12.6	50.0	32.6	15	>4 (P)				
44	8.0	36.0	33.3	54.0	32.9	13	>4 (P)				
46	42.0	50.9	10.1	9.0	28.0	10	>4 (P)				
48	12.0	7.9	25.9	48.4	23.6	6	4				
50	10.9	2.0	36.0	34.0	20.7	5	4				
52	20.0	0	9.0	23.4	13.1	5	4				
54	3.0	11.0	4.0	9.0	6.8	10	4				
56	12.0	15.3	2.0	2.0	7.8	14	4				
58	0	0	0	0	0	14	4				
TOTAL	281.5	291.1	224.3	348.6	286.6						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 0.5 at 150 min
Preheater Deposit Code: 3P
TDR Spun Deposit Rating: 15 at 40

1% SULFUR REFEREE DIESEL AL-13619-F AT 204°C (400°F)—TEST 5143*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	3	0				
04	1.8	0	1.7	0	0.9	1	0				
06	2.5	0	0	1.1	0.9	0	0				
08	0	0	0	0	0	0	0				
10	0	0	0	0	0	0	0				
12	0	0	0	0	0	0	0				
14	3.6	0	0	2.3	1.5	0	0				
16	0	0	2.2	0	0.6	0	0				
18	0	0	1.4	0	0.4	0	0				
20	0	0	3.0	2.4	1.4	0	0				
22	0	0	0	3.5	0.9	0	0				
24	0	0	0	3.7	0.9	1	0				
26	1.8	0	0	0	0.5	2	0				
28	0	0	3.3	0	0.8	6	0				
30	9.7	0	8.7	8.3	6.7	13	3				
32	12.5	1.0	7.1	15.2	9.0	14	4				
34	10.2	0	26.9	10.9	12.0	8	4				
36	26.4	0	2.3	12.2	10.2	5	4				
38	15.2	0	2.0	5.6	5.7	7	>4 (P)				
40	7.1	22.8	35.2	39.0	26.0	10	>4 (P)				
42	18.9	32.9	34.8	36.2	30.7	11	>4 (P)				
44	30.0	6.2	41.5	31.0	31.7	11	>4 (P)				
46	30.7	18.3	23.7	4.3	19.1	9	>4 (P)				
48	36.5	9.6	[illegible]	36.2	34.6	6	4				
50	30.2	2.9	39.6	30.2	[illegible]	6	4				
52	12.3	22.7	21.1	6.1	20.6	7	4				
54	22.2	22.0	20.7	[illegible]	22.8	11	4				
56	20.2	17.1	17.8	1.8	13.2	18	4				
58	22.1	7.7	1.2	7.0	10.0	23	4				
TOTAL	333.9	161.0	333.8	303.3	288.6						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 0
Preheater Deposit Code: 3P
TDR Spun Deposit Rating: 19 at 32

1% SULFUR REFEREE DIESEL AL-13619-F AT 218°C (425°F)—TEST 504T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	3	0				
04	0	0	0	0	0	1	0				
06	0	0	0	0	0	0	0				
08	0	0	0	0	0	0	0				
10	0	0	0	0	0	0	0				
12	0	0	0	0	0	0	0				
14	0	0	0	0	0	0	0				
16	0	0	2.9	4.8	1.9	0	0				
18	0	0	3.5	2.9	1.6	0	0				
20	0	0	3.7	2.4	2.0	2	1				
22	3.7	2.6	10.0	2.4	4.7	6	3				
24	2.4	3.0	2.0	2.3	2.4	11	4				
26	0	25.3	3.6	25.0	13.5	10	4				
28	34.6	13.0	15.8	3.4	16.7	5	4				
30	52.7	68.3	8.7	9.6	34.8	9	>4 (P)				
32	8.5	9.2	3.1	48.9	17.4	17	>4 (P)				
34	52.5	43.7	47.7	33.8	44.4	16	>4 (P)				
36	105.4	93.0	5.1	91.1	73.7	16	>4 (P)				
38	94.2	83.4	78.8	95.2	87.9	18	>4 (P)				
40	106.4	91.0	106.6	97.2	100.3	19	>4 (P)				
42	142.0	109.7	69.7	122.6	111.0	19	>4 (P)				
44	90.1	97.0	95.7	112.5	98.8	18	>4 (P)				
46	85.4	104.4	77.4	65.8	83.3	17	>4 (P)				
48	44.9	116.5	55.4	67.0	71.0	16	>4 (P)				
50	29.8	56.4	5.2	76.8	41.6	18	>4 (P)				
52	6.3	50.4	23.8	5.5	21.5	15	>4 (P)				
54	4.1	47.1	10.1	36.6	24.5	11	>4 (P)				
56	5.2	5.2	19.1	36.6	16.5	10	4				
58	1.9	1.8	7.3	8.7	4.9	12	4				
TOTAL	870.1	1021.0	637.0	949.1	874.4						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 1 at 150 min
Preheater Deposit Code: >3P
TDR Spun Deposit Rating: 19 at 42

1% SULFUR REFEREE DIESEL AL-13619-F AT 218°C (425°F)—TEST 519T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	6	0				
04	6.1	0	0	0	1.5	3	0				
06	23.[illegible]	2.0	1.0	0	6.5	2	0				
08	8.0	1.0	0	0	2.3	2	0				
10	1.[illegible]	0	0	0	0.3	1	0				
12	[illegible]	0	0	1.0	1.1	1	0				
14	4.9	0	[illegible]	2.3	[illegible]	1	[illegible]				
16	0	0	0	0	0	1	0				
18	5.0	8.6	0	1.0	3.7	1	0				
20	0	2.0	3.8	0	1.5	[illegible]	0				
22	25.0	5.8	0	6.0	9.2	6	3				
24	17.3	0	0	2.0	4.8	16	4				
26	14.2	5.0	8.1	28.7	14.0	8	4				
28	37.8	49.1	32.1	50.1	42.3	[illegible]	>4 (P)				
30	47.5	66.6	17.5	34.9	41.6	20	4 (P)				
32	50.6	100.6	67.8	60.9	70.0	17	>4 (P)				
34	65.5	50.1	82.9	[illegible]	67.2	18	>4 (P)				
36	95.0	99.1	102.8	103.3	100.1	21	>4 (P)				
38	101.7	95.7	111.6	60.0	92.3	22	>4 (P)				
40	100.4	[illegible]	50.0	128.3	92.5	23	>4 (P)				
42	103.0	100.9	[illegible]	119.9	84.9	24	[illegible]				
44	121.8	[illegible]	[illegible]	25.0	89.6	24	>4 (P)				
46	95.3	[illegible]	80.9	[illegible]	79.6	23	>4 (P)				
48	34.2	[illegible]	88.4	[illegible]	63.1	23	>4 (P)				
50	32.4	52.7	86.0	70.1	67.8	22	>4 (P)				
52	12.0	[illegible]	65.5	[illegible]	[illegible]	19	3				
54	8.7	18.8	74.0	56.3	27.0	16	3				
56	9.0	10.0	16.0	50.0	15.8	17	4				
58	0	0	[illegible]	0	0	22	4				
TOTAL	1030.8	1067.0	895.5	1010.3	998.9						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 4 at 150 min
Preheater Deposit Code: >3P
TDR Spun Deposit Rating: 24 at 44

1% SULFUR REFEREE DIESEL AL-13619-F AT 218°C (425°F)--TEST 524T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	6	0				
04	2.8	0	2.9	0	1.4	3	0				
06	0	0	0	2.4	0.6	4	0				
08	0	0	0	0	0	3	0				
10	0	0	0	0	0	3	0				
12	0	0	0	2.8	0.7	3	0				
14	0	0	0	0	0	3	0				
16	0	0	0	3.6	0.9	4	0				
18	0	0	0	1.7	0.4	4	0				
20	0	0	0	2.5	0.7	6	0				
22	0	0	0	1.9	0.5	10	0				
24	2.6	3.2	0	2.5	2.1	17	3	0 µm		0.09 µm	0.09 µm
26	3.6	20.0	9.1	7.2	10.0	14	4				
28	23.0	15.2	24.1	3.5	16.5	8	4				
30	39.8	29.8	32.2	43.9	36.4	15	>4 (P)	0.09 µm		0.09 µm	0.09 µm
32	2.2	10.0	3.6	56.3	24.5	23	>4 (P)				
34	50.3	42.4	75.7	70.0	59.6	18	>4 (P)	0.196 µm Auger	0.12 µm	0.19 µm	0.19 µm
36	54.6	50.9	104.6	63.1	68.3	18	>4 (P)				
38	106.0	100.0	23.0	99.6	82.2	20	>4 (P)				
40	98.2	86.2	118.6	98.8	100.5	20	>4 (P)	0.28 µm Auger	0.23 µm	0.37 µm	
42	84.7	101.9	95.5	103.0	96.3	20	>4 (P)				
44	106.3	30.2	118.6	105.2	90.1	17	>4 (P)			0.32 µm	0.32 µm
46	71.8	78.5	100.3	13.3	66.0	17	>4 (P)	0.18 µm Auger			
48	99.0	100.0	74.5	63.3	84.2	17	>4 (P)				
50	89.7	4.0	52.1	56.1	50.5	17	>4 (P)				
52	14.0	10.3	5.2	8.7	9.6	17	>4 (P)				
54	6.0	36.6	37.2	33.5	28.8	14	>4 (P)				
56	2.0	3.8	4.3	30.6	10.2	12	4				
58	0	7.0	5.3	19.7	7.9	12	4				
TOTAL	482.6	720.0	886.8	855.0	848.9						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 2 at 150 min
Preheater Deposit Code: >3P
TDR Spun Deposit Rating: 20 at 40

1% SULFUR REFEREE DIESEL AL-13619-F AT 232°C (450°F)--TEST 502T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	2	0				
04	0	0	0	0	0	1	0				
06	0	0	0	0	0	0	0				
08	0	0	0	0	0	1	0				
10	0	0	0	0	0	1	0				
12	9.6	0	1.0	0	2.7	1	0				
14	0	0	0	0	0	1	0				
16	0	0	0	0	0	2	0				
18	0	0	3.3	0	0.8	6	3				
20	0	0	2.4	5.3	1.9	14	4				
22	1.7	1.2	3.0	4.1	2.5	8	4				
24	9.8	19.2	1.6	3.3	8.5	9	>4 (P)				
26	10.2	0	34.2	40.5	21.2	18	>4 (P)				
28	2.3	38.0	38.7	74.9	38.5	16	>4 (P)				
30	6.3	88.3	44.6	49.1	47.1	22	>4 (P)				
32	21.5	76.3	103.7	8.5	52.5	24	>4 (P)				
34	77.4	53.1	70.0	100.3	82.7	27	>4 (P)				
36	135.1	85.5	121.7	5.7	85.9	30	>4 (P)				
38	103.2	102.8	104.1	122.6	108.2	35	>4 (P)				
40	106.5	106.4	106.9	149.5	117.2	41	4				
42	104.3	56.4	146.1	151.1	114.5	42	4				
44	116.8	17.0	106.4	132.	92.7	45	4				
46	141.3	147.8	111.1	130.7	132.2	45	4				
48	112.8	110.2	127.8	136.5	114.3	43	4				
50	100.4	131.1	103.4	25.2	90.0	40	4				
52	82.1	40.7	52.6	64.0	59.9	36	4				
54	5.1	64.4	38.2	33.5	35.4	30	4				
56	7.6	82.4	92.3	11.3	26.9	27	3				
58	5.0	29.0	2.6	24.5	15.8	29	3				
TOTAL	1135.6	1265.8	1332.6	1290.4	1247.4						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 11.5 at 150 min
Preheater Deposit Code: 4
TDR Spun Deposit Rating: 45 at 44

1% SULFUR REFEREE DIESEL AL-13619-F AT 232°C (450°F)—TEST 517T*

Tube Station	Dielectric Strength, Volts					MARK 9 TDR	Visual Rating	Thickness Measurement			
	0°	90°	180°	270°	Dielectric Average			0°	90°	180°	270°
02	0	0	0	0	0	4	0				
04	0	0	0	0	0	2	0				
06	0	0	0	0	0	2	0				
08	0	0	0	0	0	1	0				
10	0	0	0	0	0	1	0				
12	0	0	0	0	0	1	0				
14	0	0	0	4.0	1.0	1	0				
16	0	0	0	1.0	0.3	2	0				
18	2.7	1.0	2.1	1.0	1.7	3	0				
20	3.0	1.0	2.1	1.0	1.8	9	3				
22	3.0	2.1	1.0	4.0	2.5	13	5				
24	2.0	2.3	30.0	6.0	10.1	7	4				
26	2.0	68.0	10.0	72.5	38.1	17	>4 (P)				
28	8.0	47.0	44.0	64.3	40.8	16	>4 (P)				
30	77.6	80.0	44.4	98.1	75.0	21	>4 (P)				
32	121.4	73.0	63.3	127.0	96.7	24	>4 (P)				
34	133.7	108.2	100.0	107.0	112.2	27	>4 (P)				
36	149.9	144.0	106.9	137.8	134.7	29	>4 (P)				
38	133.3	155.9	139.0	249.6	174.5	35	4				
40	167.3	185.0	170.9	224.9	187.0	41	4				
42	180.4	186.5	290.7	265.0	216.7	44	4				
44	168.0	201.0	254.9	230.0	208.5	45	4				
46	189.5	156.7	111.9	166.0	156.0	45	4				
48	145.9	161.5	175.9	129.0	153.0	43	4				
50	90.0	112.9	150.9	102.1	114.0	39	4				
52	160.0	106.2	101.8	125.9	123.5	35	4				
54	22.8	90.0	20.9	120.8	63.6	29	4				
56	26.6	84.6	8.7	103.7	55.9	25	3				
58	120.0	14.0	74.3	54.6	65.7	21	2				
TOTAL	1911.3	1982.7	1863.7	2375.1	2033.3						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 7 at 150 min
Preheater Deposit Code: 4
TDR Spun Deposit Rating: 45 at 44

1% SULFUR REFEREE DIESEL AL-13619-F AT 232°C (450°F)—TEST 520T*

Tube Station	Dielectric Strength, Volts					MARK 9 TDR	Visual Rating	Thickness Measurement			
	0°	90°	180°	270°	Dielectric Average			0°	90°	180°	270°
02	0	0	0	0	0	2	0				
04	0	0	0	0	0	1	0				
06	0	0	0	0	0	1	0				
08	0	0	0	0	0	1	0				
10	0	0	0	0	0	1	0				
12	0	0	2.9	0	0.7	1	0				
14	0	0	0	0	0	1	0				
16	0	0	0	0	0	2	0				
18	0	2.7	4.5	0	1.7	4	0				
20	0	0	0	1.8	0.5	11	0				
22	2.6	0	0	2.0	1.2	14	3				
24	2.5	32.8	12.7	5.0	13.3	6	4		0.09 µm	0.05 µm	
26	40.8		3.7	2.5	11.8	18	>4 (P)				
28	56.5	47.4	0	56.0	40.0	16	>4 (P)		0.10 µm		
30	74.2	2.9	89.7	0	41.7	23	>4 (P)				
32	89.6	56.0	106.4	100.4	88.1	26	>4 (P)				
34	94.5	114.4	130.6	103.7	111.3	30	>4 (P)	0.293 µm Auger	0.32 µm	0.32 µm	0.32 µm
36	141.6	135.7	20.0	121.6	104.7	35	>4 (P)				
38	106.5	169.5	146.1	193.8	154.0	40	4			0.45 µm	
40	205.1	206.4	196.7	223.6	208.0	43	4				
42	236.6	179.1	188.8	256.5	215.3	45	4	0.657 µm Auger	0.34 µm	0.58 µm	0.67 µm
44	145.0	160.5	205.2	216.2	181.7	45	4				
46	100.5	225.4	203.3	224.9	188.5	44	4				
48	150.5	172.5	122.2	174.4	154.9	51	4	0.413 µm Auger			
50	62.7	113.9	122.1	215.7	128.6	38	4				
52	46.3	134.8	26.0	105.1	78.1	33	4				
54	32.4	9.1	6.0	69.0	34.1	28	4				
56	1.8	3.1	76.1	6.2	22.1	26	1				
58	5.1	1.1	3.3	6.6	4.1	21	2				
TOTAL	1619.2	1766.9	1666.3	2085.0	1784.6						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 47 at 150 min
Preheater Deposit Code: 4
TDR Spun Deposit Rating: 45 at 44

1% SULFUR REFEREE DIESEL AL-13619-F AT 260°C (500°F)—TEST 501J*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	2	0				
04	3.1	0	0	0	0.8	1	0				
06	0	2.0	2.0	0	1.0	2	0				
08	4.0	3.7	2.5	0	2.3	1	0				
10	4.7	7.1	3.1	0	4.2	2	0				
12	5.3	5.5	15.2	0	6.4	5	0				
14	11.3	10.8	14.4	7.0	10.9	7	4				
16	4.5	1.6	3.7	5.8	4.6	13	4				
18	36.7	15.3	79.2	42.1	33.3	4	>4 (P)				
20	27.9	4.8	61.8	33.2	31.9	18	>4 (P)				
22	62.4	94.6	77.6	95.6	82.6	20	>4 (P)				
24	100.7	72.7	46.8	49.3	67.4	27	>4 (P)				
26	123.3	151.0	148.6	190.2	153.8	33	>4 (P)				
28	128.7	150.5	253.9	190.3	180.9	43	>4 (P)				
30	191.5	226.6	295.2	307.0	255.1	49	>4 (P)				
32	434.0	500.1	461.0	400.2	453.9	50	4				
34	452.2	513.6	465.2	556.4	496.9	50	4				
36	500.8	451.7	501.0	519.0	493.3	50	4				
38	500.9	515.2	511.2	349.3	[illegible]	50	4				
40	506.7	512.4	533.8	473.7	507.2	49	4				
42	424.2	483.3	530.9	468.5	477.2	49	4				
44	540.3	514.6	496.2	460.2	502.8	49	4				
46	435.4	506.9	490.2	450.1	473.7	48	4				
48	42.5	433.2	425.7	404.3	326.9	48	4				
50	330.0	365.8	421.1	382.2	374.8	47	4				
52	249.8	147.4	155.7	142.8	174.2	45	4				
54	230.7	21.4	110.4	82.7	116.3	42	4				
56	197.7	126.3	8.9	54.9	97.0	38	4				
58	11.9	12.1	180.6	74.6	69.8	36	4				
TOTAL	5440.2	5855.9	6259.8	5940.0	5923.7						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 48 min
Preheater Deposit Code: >4
TDR Spun Deposit Rating: 50 at 34

1% SULFUR REFEREE DIESEL AL-13619-F AT 260°C (500°F)—TEST 516J*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	1.1	6.8	0	0	1.5	3	0				
04	0.4	3.0	0	0	0.9	2	0				
06	0.4	0.4	0	0	0.2	1	0				
08	0.4	0.4	0	0	0.2	1	0				
10	0.4	0.4	0	0	0.2	1	0				
12	0.4	0.4	0	0	0.2	2	0				
14	0.4	2.9	3.6	0	1.7	9	4				
16	2.0	0.4	3.6	11.8	4.5	11	4				
18	1.5	0.4	3.4	17.8	5.8	17	>4 (P)				
20	7.0	101.0	45.1	52.0	51.3	20	>4 (P)				
22	0.4	84.5	78.9	86.5	62.5	25	>4 (P)				
24	9.2	85.1	100.1	105.0	74.9	33	>4 (P)				
26	200.0	163.4	119.2	120.1	150.7	45	>4 (P)				
28	352.0	195.3	356.0	300.4	300.9	49	4				
30	480.0	513.0	180.1	449.0	405.5	50	4				
32	495.0	506.0	333.0	181.5	378.9	50	4				
34	303.0	445.0	192.7	401.1	336.0	49	4				
36	455.0	529.0	340.0	73.1	349.3	49	4				
38	400.0	337.0	270.3	127.7	288.8	49	4				
40	246.0	479.0	251.2	153.1	282.3	48	4				
42	224.0	429.0	200.1	191.3	261.1	47	4				
44	154.0	236.7	[illegible]	[illegible]	[illegible]	45	4				
46	75.0	81.1	206.0	125.3	121.4	44	4				
48	1.6	6.5	180.0	10.5	49.2	42	4				
50	6.6	31.8	270.9	6.3	78.9	38	3				
52	106.0	1.5	56.0	36.2	49.9	35	3				
54	55.2	1.1	93.0	26.1	44.4	29	3				
56	50.3	1.4	130.0	5.2	33.0	23	3				
58	5.7	1.4	0	15.1	8.2	20	2				
TOTAL	3635.7	4261.9	3622.4	2695.5	3560.6						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 129 min
Preheater Deposit Code: >4
TDR Spun Deposit Rating: 50 at 32

1% SULFUR REFEREE DIESEL AL-13619-F AT 260°C (500°F)—TEST 5183*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	2.3	2.2	2.6	1.8	8	0				
04	2.7	2.2	3.7	2.7	2.8	5	0				
06	2.1	2.2	0	1.2	1.4	4	0				
08	2.1	2.3	2.4	1.3	2.0	4	0				
10	1.0	1.3	4.1	2.0	2.9	5	0				
12	3.4	4.5	5.0	5.7	4.7	5	1				
14	6.1	7.4	0	1.6	3.8	12	2				
16	24.1	18.3	10.6	10.6	15.9	15	4	0.08 m			
18	30.1	32.2	47.1	21.7	32.8	15	>4 (P)				
20	76.4	29.3	78.6	62.2	61.6	19	>4 (P)				
22	71.8	156.4	106.4	95.0	107.6	25	>4 (P)		0.32 μm	0.32 μm	0.32 μm
24	76.6	142.0	97.3	135.0	112.7	30	>4 (P)				
26	138.0	128.6	230.4	181.8	174.7	37	>4 (P)			0.68 μm	0.68 μm
28	125.2	131.0	30.5	328.0	153.7	46	>4 (P)				
30	139.5	244.0	556	378.0	>341.9	49	>4 (P)		0.73 μm		
32	414.0	>556	>556	339.0	>466.3	50	4	3.68 μm Auger		1.90 μm	
34	356.0	>556	>556	390.0	>464.5	50	4				
36	335.0	>556	>556	338.0	>496.3	50	4				
38	>556	>556	>556	551.0	>554.8	50	4				
40	>556	384.0	>556	340.0	>459.0	50	4				
42	>556	384.0	>556	341.0	>309.3	50	4	3.44 μm Auger			
44	>556	431.0	448.0	473.0	>477.0	49	4		1.22 μm		
46	335.0	>556	335.0	337.0	>446.0	49	4				
48	486.0	556	449.0	82.0	393.3	47	4				
50	114.0	244.8	356.0	2.7	179.4	43	4		0.77 μm		
52	37.9	260.0	136.0	1.6	108.9	43	4				
54	39.5	103.2	30.7	3.6	44.3	40	4				
56	4.6	10.5	4.3	1.2	5.2	38	4				
58	6.6	4.0	12.1	3.0	6.4	38	4				
TOTAL	5321.7	6081.9	6302.4	4832.9	5635.2						

*JFTOT, D 3241

Change in Pressure Drop, mm of Hg: 125 at 28 min

Preheater Deposit Code: >4

TDR Spun Deposit Rating: 50 at 38

CAT I-H AL-13618-F AT 204°C (400°F)—TEST 496T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	3	0				
04	0	0	0	0	0	1	0				
06	0	0	0	0	0	0	0				
08	0	0	0	0	0	-1	0				
10	0	0	0	0	0	-1	0				
12	0	0	0	0	0	-2	0				
14	0	0	0	0	0	-2	0				
16	0	0	0	0	0	-2	0				
18	0	0	0	0	0	-2	0				
20	0	0	0	0	0	-1	0				
22	0	0	0	0	0	-1	0				
24	0	0	0	0	0	-1	0				
26	0	0	0	1.9	0.5	-1	0				
28	10.0	0	0	0	2.5	-1	0				
30	6.0	0	0	0	1.5	0	0				
32	2.7	0	0	1.5	1.1	0	0				
34	0	0	0	0	0	0	0				
36	0	0	0	0	0	0	0				
38	0	0	0	0	0	0	0				
40	0	0	0	0	0	0	0				
42	0	0	2.0	3.4	1.4	0	0				
44	0	0	0	0	0	0	0				
46	0	0	0	3.3	0.8	0	0				
48	0	0	0	0	0	0	0				
50	0	0	0	2.0	0.5	0	0				
52	0	0	0	0	0	0	0				
54	0	0	0	0	0	1	0				
56	0	0	0	0	0	3	0				
58	0	0	0	0	0	6	0				
TOTAL	18.7	0	2.0	12.1	8.3						

*JFTOT, D 3241
- Change in Pressure Drop, mm of Hg: 0
- Preheater Deposit Code: 0
- TDR Spun Deposit Rating: 0

CAT I-H AL-13618-F AT 204°C (400°F)—TEST 505J*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	2	0				
04	0	0	0	0	0	1	0				
06	0	0	0	0	0	0	0				
08	1.8	0	0	0	0.5	0	0				
10	2.0	0	0	0	0.5	0	0				
12	0	0	0	0	0	0	0				
14	0	0	0	2.5	0.6	0	0				
16	0	0	0	0	0	0	0				
18	0	0	0	0	0	0	0				
20	0	0	0	4.0	1.0	0	0				
22	0	0	0	0	0	1	0				
24	2.0	0	0	0	0.5	1	0				
26	0	0	0	0	0	1	0				
28	4.6	0	0	0	1.2	1	0				
30	0	0	0	2.0	0.5	2	0				
32	4.0	0	3.5	7.0	3.6	2	0				
34	0	2.4	1.8	1.0	1.3	2	0				
36	2.0	0	0	0	0.5	2	0				
38	1.7	0	0	0	0.4	3	0				
40	2.7	0	1.9	0	1.2	2	0				
42	2.0	1.2	0	0	0.8	2	0				
44	1.9	0	2.4	0	1.1	2	0				
46	1.2	0	1.9	0	0.8	2	0				
48	0	0	2.2	0	0.6	2	0				
50	6.3	0	2.8	0	2.3	1	0				
52	0	2.5	0	4.0	1.6	2	0				
54	0	0	0	0	0	2	0				
56	0	0	0	3.1	1.3	2	0				
58	0	0	0	2.0	0.5	4	0				
TOTAL	32.3	6.1	16.5	27.6	20.8						

*JFTOT, D 3241
- Change in Pressure Drop, mm of Hg: 0
- Preheater Deposit Code: 0
- TDR Spun Deposit Rating: 3 at 38

CAT 1-H AL-13618-F AT 204°C (400°F)—TEST 5083*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	0	0				
04	0	0	0	0	0	0	0				
06	0	0	0	0	0	0	0				
08	0	0	2.0	0	0.5	0	0				
10	0	0	0	0	0	0	0				
12	0	0	0	0	0	0	0				
14	0	0	0	0	0	0	0				
16	0	0	2.0	0	0.5	0	0				
18	0	0	0	0	0	0	0				
20	0	0	0	0	0	0	0				
22	0	0	3.5	0	0.9	0	0				
24	0	0	0	0	0	0	0				
26	0	1.2	0	1.8	0.8	0	0				
28	0	0	0	0	0	1	0				
30	0	0	0	0	0	1	0				
32	0	0	3.5	0	0.9	1	0				
34	0	0	0	3.0	0.8	1	0				
36	0	0	0	0	0	2	0				
38	3.0	0	0	0	0.8	2	0				
40	0	0	0	0	0	1	0				
42	0	0	5.0	0	1.3	1	0				
44	0	0	3.9	1.8	1.4	1	0				
46	0	1.9	0	0	0.5	1	0				
48	0	0	0	0	0	1	0				
50	0	0	0	0	0	1	0				
52	0	3.0	3.5	0	1.6	1	0				
54	0	0	0	1.2	0.3	1	0				
56	0	0	0	0	0	1	0				
58	0	0	0	0	0	3	0				
TOTAL	3.0	6.1	23.4	7.8	10.3						

*JFTOT, D 3241

Change in Pressure Drop, mm of Hg: 0

Preheater Deposit Code: 0

TDR Spun Deposit Rating: 2 at 38

CAT 1-H AL-13618-F AT 218°C (425°F)—TEST 4953*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	2	0				
04	0	0	0	0	0	0	0				
06	0	0	0	0	0	0	0				
08	0	0	0	0	0	<1	0				
10	0	0	0	0	0	0	0				
12	0	0	0	0	0	0	0				
14	3.0	0	0	0	0.8	0	0				
16	0	0	0	0	0	0	0				
18	0	0	0	0	0	0	0				
20	1.8	0	1.8	3.0	1.7	0	0				
22	0	0	0	2.8	0.7	0	0				
24	0	0	0	0	0	0	0				
26	0	0	2.0	4.8	1.7	0	0				
28	5.0	0	13.0	0	4.5	0	0				
30	3.0	0	10.3	0	3.3	1	0				
32	4.0	0	5.9	0	2.5	1	0				
34	0	10.0	6.4	0	4.1	2	0				
36	0	0	3.2	16.8	4.9	3	0				
38	1.7	3.2	1.2	0	1.5	3	0				
40	2.5	0	0	9.3	3.0	3	0				
42	6.4	0	2.2	19.2	6.5	3	0				
44	3.9	0	0	0	1.0	2	0				
46	1.3	0	1.5	9.0	3.1	2	0				
48	1.9	0	7.5	3.8	3.3	1	0				
50	0	0	0	4.6	1.2	0	0				
52	0	0	0	0	0	0	0				
54	0	0	0	0	0	0	0				
56	0	0	0	0	0	0	0				
58	1.2	0	0	0	0.3	2	0				
TOTAL	34.1	13.2	55.0	72.9	44.1						

*JFTOT, D 3241

Change in Pressure Drop, mm of Hg: 2 at 150 min

Preheater Deposit Code: <3P

TDR Spun Deposit Rating: 3 at 40

CAT I-H AL-13618-F AT 218°C (425°F)—TEST 506T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	0	0				
04	0	0	0	0	0	6	0				
06	3.2	0	0	0	0.8	3	0				
08	0	3.7	0	0	0.9	3	0				
10	3.4	0	0	0	0.9	2	0				
12	0	0	0	0	0	2	0				
14	0	0	0	0	0	2	0				
16	0	0	0	2.4	0.6	3	0				
18	5.2	7.5	2.9	3.8	4.9	3	0				
20	0	0	3.7	0	0.9	4	0				
22	3.1	3.0	1.2	7.0	3.6	4	0				
24	2.4	0	0	2.4	1.2	4	0				
26	0	0	2.4	0	0.6	5	0				
28	0	4.7	0	0	1.2	6	0				
30	0	1.6	0	0	0.4	6	0				
32	0	1.1	1.3	1.9	1.1	7	0				
34	0	2.5	0	0	0.6	7	0				
36	0	7.4	0	4.7	3.0	8	0				
38	0	6.4	0	2.9	2.3	8	0				
40	2.5	5.1	1.7	3.2	3.1	8	0				
42	0	5.1	0	3.4	2.1	8	0				
44	0	6.9	2.3	0	2.3	7	0				
46	0	5.0	6.3	10.1	5.4	7	0				
48	0	12.0	0	0	3.0	6	0				
50	1.7	17.2	0	1.9	5.2	5	0				
52	0	0	4.0	0	1.0	5	0				
54	0	5.0	0	0	1.3	4	0				
56	0	0	0	0	0	5	0				
58	0	0	0	0	0	7	0				
TOTAL	21.5	94.2	25.8	43.7	46.4						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 1 at 150 min
Preheater Deposit Code: <3
TDR Spun Deposit Rating: 8 at 40

CAT I-H AL-13618-F AT 218°C (425°F)—TEST 507T*

Tube Station	Dielectric Strength, Volts 0°	90°	180	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	1	0				
04	0	0	0	0	0	0	0				
06	0	0	0	0	0	0	0				
08	0	2.9	0	0	0.7	0	0				
10	0	0	1.0	2.3	0.8	0	0				
12	4.8	0	0	0	1.2	0	0				
14	5.9	0	0	0	1.5	0	0				
16	0	1.6	1.8	0	0.9	0	0				
18	0	6.4	6.0	0	3.1	0	0				
20	0	5.0	2.1	0	1.8	1	0				
22	0	4.0	1.7	0	1.4	1	0				
24	2.2	2.5	12.7	0	4.4	2	0				
26	0	10.2	1.3	3.9	3.9	3	0				
28	12.6	2.0	11.4	0	6.5	4	3				
30	0	4.0	4.1	3.0	2.8	4	3				
32	0	3.0	0	8.2	2.8	5	3				
34	4.3	0	0	13.6	4.5	6	3				
36	5.9	13.0	1.4	0	5.1	6	3				
38	0	2.8	6.1	0	2.2	6	3				
40	2.3	3.0	1.0	7.8	3.5	[illegible]	3				
42	20.3	0	0	3.0	5.8	6	3				
44	5.0	8.9	8.0	11.8	8.4	6	3				
46	12.0	0	3.3	15.0	7.6	5	3				
48	3.3	4.0	9.1	2.5	5.2	4	3				
50	2.4	0	[illegible]	0	[illegible]	3	3				
52	0	3.4	2.5	8.5	[illegible]	[illegible]	2				
54	1.8	0	0	5.4	1.8	[illegible]	0				
56	3.8	0	0	6.7	2.6	[illegible]	0				
58	0	0	2.0	0	0.5	4	0				
TOTAL	88.6	99.1	[illegible]	91.7	84.3						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 0
Preheater Deposit Code: <3
TDR Spun Deposit Rating: 7 at 40

CAT 1-H AL-13618-F AT 232°C (450°F)—TEST 493J*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	0	0				
04	0	0	0	0	0	-1	0				
06	0	0	0	0	0	-1	0				
08	0	0	0	0	[illegible]	-2	0				
10	3.1	0	0	1.3	1.2	-2	0				
12	0	0	6.0	2.7	1.7	-1	0				
14	1.2	0	0	0	0.3	-1	0				
16	0	0	0	0	0	-1	0				
18	0	0	2.0	0	0.5	-1	1				
20	0	0	0	0	0	0	2				
22	4.0	0	0	2.8	1.7	0	2				
24	0	1.0	5.6	0	1.7	0	3				
26	12.0	0	0	0	3.0	2	3				
28	3.0	0	2.9	0	1.5	3	3				
30	2.3	0	9.7	1.4	3.4	5	3				
32	3.7	2.0	0	1.6	1.8	7	4				
34	18.0	8.5	3.4	0	7.5	9	4				
36	3.5	4.0	3.6	3.6	3.7	10	4				
38	1.0	0	6.9	10.3	4.6	10	4				
40	0	1.9	3.9	3.3	2.3	10	4				
42	6.4	2.7	0	2.9	3.0	10	4				
44	0	0	2.9	1.6	1.1	8	4				
46	3.2	2.2	7.3	1.9	3.7	7	4				
48	0	0	12.0	5.3	4.3	5	4				
50	2.0	0	2.0	0	1.0	3	3				
52	0	3.0	5.4	1.4	2.5	2	2				
54	0	4.4	19.0	2.0	6.4	0	1				
56	0	5.5	7.5	1.9	3.7	0	0				
58	0	0	4.9	0	1.2	4	0				
TOTAL	63.4	35.2	103.0	44.2	61.8						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 2 at 150 min
Preheater Deposit Code: 3
TDR Spun Deposit Rating: 10 at 40

CAT 1-H AL-13618-F AT 232°C (450°F)—TEST 498T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	0	0				
04	0	0	0	0	0	0	0				
06	0	4.1	0	0	1.0	0	0				
08	0	0	0	0	0	-1	0				
10	1.6	1.2	0	0	0.7	-1	0				
12	0	0	2.8	3.0	1.5	-1	0				
14	0	0	0	0	0	0	0				
16	0	3.4	0	0	0.9	0	0				
18	0	0	0	0	0	0	0				
20	0	0	0	3.9	1.0	0	0				
22	2.2	0	0	0	0.6	0	0				
24	0	0	3.5	1.9	1.4	0	0				
26	5.1	3.1	0	3.0	2.8	2	0	0 μm	0 μm	0 μm	0 μm
28	2.9	0	0	2.4	1.3	3	0				
30	3.7	0	0	8.5	3.1	5	2				
32	8.9	0	1.5	5.4	4.5	6	2				
34	6.4	0	0	4.3	2.7	8	3	0 μm	0 μm	0 μm	0 μm
36	22.5	4.2	0	0	6.9	9	3				
38	7.3	1.6	3.0	3.1	3.3	9	3				
40	10.6	21.8	12.4	0	11.2	9	3	0.05 μm	0.05 μm	0 μm	0 μm
42	0	3.4	9.4	19.9	8.2	9	3				
44	0	13.8	0	0	3.5	8	3				
46	0	[illegible]	5.1	[illegible]	3.0	6	2				
48	0	0	19.7	1.8	5.4	4	2				
50	2.1	0	0	6.1	2.1	2	2				
52	0	[illegible]	3.0	1.0	[illegible]	1	0				
54	1.8	1.8	6.0	2.0	2.9	0	0				
56	[illegible]	0	[illegible]	0	0.3	1	0				
58	2.1	[illegible]	0	0	[illegible]	[illegible]	0				
TOTAL	[illegible]	[illegible]	59.6	69.5	[illegible]						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 0
Preheater Deposit Code: 3
TDR Spun Deposit Rating: 9 at 40

CAT 1-H AL-13618-F AT 232°C (450°F)—TEST 511T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	2	0				
04	0	0	0	0	0	2	0				
06	0	0	0	0	0	1	0				
08	0	0	0	0	0	1	0				
10	0	0	0	0	0	1	0				
12	0	0	0	2.5	0.6	1	0				
14	0	0	0	0	0	1	0				
16	0	0	0	2.0	0.5	2	0				
18	0	2.5	0	0	0.6	2	0				
20	1.5	1.2	0	0	0.7	3	0				
22	3.1	0	0	0	0.8	3	0				
24	0	0	0	7.9	2.0	4	0				
26	0	0	5.8	0	1.4	5	0				
28	9.6	2.0	6.8	5.1	5.9	7	2				
30	2.5	0	0	7.5	2.5	5	2				
32	2.9	2.0	10.5	11.1	6.6	10	3				
34	3.2	5.7	3.2	9.0	5.3	12	3				
36	2.0	1.6	1.6	15.6	5.0	13	3				
38	2.7	0	25.2	5.9	8.5	14	3				
40	0	14.7	6.6	18.8	10.0	14	3				
42	4.6	2.2	5.2	6.5	4.6	14	3				
44	9.7	7.0	12.9	13.9	10.9	13	3				
46	6.5	0	11.9	5.0	5.8	12	3				
48	1.7	0	0	14.5	4.1	10	3				
50	0	0	8.1	11.3	4.9	8	2				
52	0	10.3	16.5	17.6	11.1	6	2				
54	0	14.2	8.0	3.6	6.5	5	0				
56	0	5.4	0	3.4	2.2	4	0				
58	0	0	2.5	2.3	1.2	5	0				
TOTAL	52.1	70.0	126.4	134.2	101.0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 0
Preheater Deposit Code: 3
TDR Spun Deposit Rating: 14 at 40

CAT 1-H AL-13618-F AT 260°C (500°F)—TEST 498T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	1	0				
04	0	0	0	0	0	0	0				
06	0	0	0	0	0	0	0				
08	0	0	0	0	0	0	0				
10	0	0	0	0	0	1	0				
12	0	0	0	0	0	1	0				
14	0	0	0	0	0	2	1				
16	0	2.8	0	6.7	2.4	2	2				
18	0	1.5	0	2.4	1.0	4	2				
20	9.3	6.6	7.0	10.4	8.3	6	3				
22	0	0	19.4	20.6	10.0	9	3				
24	5.1	0	0	5.2	2.6	11	3				
26	0	0	2.9	8.2	2.7	11	4				
28	5.6	3.5	0	18.0	6.8	9	4				
30	0	0	10.1	0	2.5	7	4				
32	17.9	2.9	5.9	5.5	8.1	5	4				
34	7.2	30.4	11.9	0	12.4	4	4				
36	4.7	4.4	8.9	0	4.5	3	4				
38	19.2	3.3	25.8	17.9	16.6	3	4				
40	3.2	38.0	15.0	0	14.1	3	4				
42	17.5	12.0	1.6	0	7.8	4	4				
44	[illegible]	34.0	53.6	27.9	29.7	4	4				
46	[illegible]	2.4	6.3	3.1	4.5	4	4				
48	11.6	3.3	40.0	25.4	20.2	6	4				
50	25.3	2.8	4.4	2.1	8.7	8	4				
52	4.0	0	6.0	4.1	3.5	10	4				
54	3.5	0	15.7	2.8	5.5	8	4				
56	1.1	2.4	0	0	0.9	6	3				
58	0	0	3.0	0	0.8	11	3				
TOTAL	163.5	150.3	[illegible]	160.3	[illegible]						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 125 min
Preheater Deposit Code: 4P
TDR Spun Deposit Rating: 11 at 26

CAT 1-H AL-13618-F AT 260°C (500°F)—TEST 509T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	2	0				
04	0	0	0	0	0	2	0				
06	0	0	0	0	0	2	0				
08	1.6	0	0	0	0.4	2	0				
10	1.4	3.9	0	0	1.3	2	0				
12	0	4.2	0	0	1.1	2	0				
14	0	5.4	0	0	1.4	3	0				
16	0	0	0	0	0	3	0				
18	0	4.2	0	0	1.1	5	0				
20	0	3.4	1.8	0	1.3	7	0				
22	4.0	0	0	13.0	5.0	9	1				
24	6.1	0	0	5.0	2.8	13	3				
26	0	0	0	0	0	15	3				
28	2.7	3.4	13.0	2.5	5.3	16	4				
30	29.5	3.2	3.6	20.6	14.2	12	4				
32	0	2.2	12.5	5.6	5.1	9	4				
34	2.0	1.1	2.5	44.2	12.5	8	4				
36	29.4	6.6	4.7	54.6	23.8	8	4				
38	0	25.7	30.5	11.8	17.0	8	4				
40	3.0	25.2	0	46.8	18.8	9	4				
42	32.3	20.5	50.6	60.8	41.0	9	4				
44	6.4	2.9	7.2	50.3	16.7	9	4				
46	6.1	33.5	14.4	56.3	27.6	10	4				
48	7.4	0	34.4	34.6	19.1	12	4				
50	52.3	4.1	2.9	3.5	15.7	14	4				
52	3.2	6.3	6.9	3.0	4.9	15	3				
54	9.5	3.9	7.1	3.5	6.0	13	3				
56	0	0	0	5.8	1.5	8	3				
58	0	0	0	0	0	5	0				
TOTAL	197.2	159.7	191.9	423.9	243.2						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 42 at 150 min
Preheater Deposit Code: >4
TDR Spun Deposit Rating: 15 at 52

CAT 1-H AL-13618-F AT 260°C (500°F)—TEST 510T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	2	0				
04	0	0	0	0	0	1	0				
06	0	0	0	0	0	1	0				
08	0	0	0	0	0	1	0				
10	2.2	0	0	0	0.6	1	0				
12	3.3	0	0	0	0.8	2	0				
14	0	4.0	6.4	0	2.6	2	0				
16	1.8	4.3	0	0	1.5	4	0				
18	2.6	2.9	2.2	0	1.9	5	1				
20	0	2.2	3.4	0	1.4	9	2				
22	0	0	0	5.6	1.4	11	3	0 μm	0 μm	0 μm	0 μm
24	2.4	7.9	20.6	3.2	8.6	14	3				
26	0	10.4	3.6	0	3.5	14	4				
28	2.7	[illegible]	23.8	2.2	9.1	11	4				
30	0	2.9	3.0	2.9	2.7	7	4				
32	3.7	0	27.3	1.9	8.8	5	4	0 μm	0 μm	0.06 μm	0 μm
34	2.8	29.2	0	42.3	18.6	6	4				
36	0	4.1	45.8	7.3	14.1	5	>4 (P)				
38	45.7	0	0	47.0	23.6	6	>4 (P)				
40	5.2	47.3	46.8	0	24.3	7	>4 (P)	0 μm	0.1 μm	0.1 μm	0.06 μm
42	0	26.8	47.7	47.3	30.3	[illegible]	>4 (P)				
44	58.3	2.7	52.4	4.1	29.4	6	>4 (P)				
46	2.0	13.0	9.9	2.8	6.9	5	4				
48	18.1	1.9	0	34.1	13.5	6	4				
50	5.1	0	2.9	2.3	2.6	10	4				
52	1.0	31.3	0	2.1	8.6	14	4				
54	4.2	[illegible]	0	1.2	1.5	12	4				
56	0	2.9	4.2	2.0	[illegible]	9	[illegible]				
58	2.6	2.8	3.3	2.2	[illegible]	9	[illegible]				
TOTAL	182.3	201.7	309.[illegible]	212.0	226.4						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 28 at 150 min
Preheater Deposit Code: >4
TDR Spun Deposit Rating: 14 at 52

CAT 1-H AL-13618-F AT 274°C (525°F)—TEST 4973*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	3	0				
04	0	0	0	0	0	3	0				
06	0	0	0	0	0	2	0				
08	2.7	0	0	0	0.7	2	0				
10	0	0	0	1.0	0.3	2	1				
12	0	0	0	0	0	2	2				
14	0	0	3.0	1.1	1.0	2	2	0 μm	0 μm	0 μm	0 μm
16	0	0	0	4.6	1.2	3	3				
18	2.9	0	0	1.1	1.0	6	3				
20	2.8	0	0	0	0.7	11	4				
22	4.1	0	0	0	1.0	10	4	0 μm	0 μm	0 μm	0 μm
24	0	0	1.5	6.3	2.0	12	4				
26	3.9	0	1.7	25.3	7.6	6	4				
28	4.6	0	4.1	2.3	2.8	8	4				
30	5.0	0	33.1	0	14.3	9	4	0 μm	0 μm	0.09 μm	0 μm
32	72.3	51.2	0	44.1	41.9	13	>4(P)				
34	2.6	42.1	0	0	11.1	17	>4(P)				
36	44.1	6.1	22.5	0	18.2	17	>4(P)				
38	3.6	94.6	50.6	76.3	55.7	19	>4(P)	0.05 μm	0.22 μm	0.13 μm	0.18 μm
40	16.6	3.1	26.6	84.1	31.6	20	>4(P)				
42	13.7	38.0	3.9	79.0	33.7	21	>4(P)				
44	106.0	5.3	84.9	52.7	62.2	20	>4(P)				
46	16.7	44.9	30.7	71.5	40.3	19	>4(P)				
48	2.7	54.6	18.4	18.8	23.6	19	>4(P)				
50	5.4	42.9	10.9	20.2	19.8	12	>4(P)				
52	3.0	6.9	0	5.7	3.9	9	4				
54	6.1	3.8	0	3.5	3.4	15	4				
56	0	2.2	2.8	3.5	2.1	18	4				
58	7.4	2.0	2.0	0	2.9	12	4				
TOTAL	320.9	397.5	316.3	499.1	382.9						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 69 min
Preheater Deposit Code: >4P
TDR Spun Deposit Rating: 21 at 42

CAT 1-H AL-13618-F AT 274°C (525°F)—TEST 4993*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	1	0				
04	0	0	0	0	0	[illegible]	[illegible]				
06	0	0	0	0	[illegible]	[illegible]					
08	0	0	[illegible]	0	[illegible]	1	[illegible]				
10	[illegible]	1.9	[illegible]	[illegible]	[illegible]	0	0				
12	0	0	0	[illegible]	[illegible]	0	0				
14	[illegible]	3.8	0	[illegible]	[illegible]	[illegible]					
16	0	0	0	[illegible]	[illegible]	0	[illegible]				
18	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
20	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					
22	0	0	[illegible]	[illegible]	[illegible]	8	[illegible]				
24	[illegible]	0	0	[illegible]	[illegible]	[illegible]	[illegible]				
26	0	0	[illegible]	0	[illegible]	10	4				
28	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
32	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
34	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18	[illegible]				
42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19	[illegible]				
44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18	[illegible]				
46	[illegible]	100.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
50	12.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
56	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
58	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]					
TOTAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 67 min
Preheater Deposit Code: >4P
TDR Spun Deposit Rating: 19 at 42

CAT 1-H AL-13618-F AT 274°C (525°F)—TEST 500T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	0	0				
04	0	0	0	0	0	0	0				
06	0	0	0	2.2	0.6	-1	0				
08	0	0	0	0	0	-1	0				
10	0	0	0	0	0	-1	0				
12	0	0	0	0	0	0	0				
14	0	0	0	0	0	0	0				
16	0	0	2.5	0	0.6	1	2				
18	0	1.0	3.5	0	1.1	4	3				
20	2.7	0	7.9	2.7	3.3	8	3				
22	3.4	0	3.9	7.8	2.5	11	4				
24	2.4	1.6	3.2	4.8	3.0	8	4				
26	3.8	0	3.7	6.4	3.5	4	4				
28	1.1	1.2	6.2	5.7	3.6	4	4				
30	11.4	21.5	3.2	8.1	11.1	10	4				
32	3.7	3.3	4.1	31.5	10.6	14	>4 (P)				
34	3.5	4.5	3.6	65.4	19.3	14	>4 (P)				
36	13.2	4.2	2.4	5.2	6.3	16	>4 (P)				
38	39.7	56.3	45.9	26.9	42.2	19	>4 (P)				
40	8.7	4.8	78.8	51.8	36.0	21	>4 (P)				
42	3.4	75.7	82.1	86.9	62.0	20	>4 (P)				
44	73.4	4.0	16.5	80.0	44.0	18	>4 (P)				
46	10.2	23.6	13.4	32.7	20.5	16	>4 (P)				
48	58.7	3.8	6.5	23.8	23.2	12	>4 (P)				
50	46.0	40.3	9.8	71.2	46.8	6	>4 (P)				
52	34.7	4.4	7.7	4.0	12.7	6	>4 (P)				
54	3.5	3.5	29.9	3.8	10.2	10	4				
56	20.4	2.2	6.4	4.7	8.4	5	3				
58	10.8	5.5	5.7	1.1	5.5	8	2				
TOTAL	342.0	261.4	346.9	521.8	177.0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 69 min
Preheater Deposit Code: >4P
TDR Spun Deposit Rating: 21 at 40

DIESEL CONTROL AL-13630-F AT 232°C (450°F)—TEST 1*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	10	0				
04	0	0	0	0	0	8	0				
06	0	0	0	0	0	7	0				
08	0	0	0	0	0	6	0				
10	0	0	0	0	0	5	0				
12	0	0	0	0	0	5	0				
14	0	0	0	0	0	4	0				
16	0	0	0	0	0	4	0				
18	0	0	0	0	0	4	0				
20	0	0	0	0	0	3	0				
22	0	0	0	0	0	4	0				
24	0	0	0	0	0	4	0				
26	0	0	0	0	0	4	0				
28	0	0	0	0	0	4	0				
30	0	0	0	0	0	4	0				
32	0	0	0	0	0	4	0				
34	0	0	0	0	0	4	0				
36	0	0	0	0	0	4	0				
38	0	0	0	0	0	4	0				
40	0	0	0	0	0	4	0				
42	0	0	0	0	0	5	0				
44	0	0	0	0	0	4	0				
46	0	0	0	0	0	5	0				
48	0	0	0	0	0	5	0				
50	0	0	0	0	0	5	0				
52	0	0	0	0	0	6	0				
54	0	0	0	0	0	6	0				
56	0	0	0	0	0	8	0				
58	0	0	0	0	0	17	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 0
Preheater Deposit Code: 1
TDR Spun Deposit Rating: 8 at 56

DIESEL CONTROL AL-13630-F AT 232°C (450°F)—TEST 2*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	9	0				
04	0	0	0	0	0	7	0				
06	0	0	0	0	0	6	0				
08	0	0	0	0	0	6	0				
10	0	0	0	0	0	6	0				
12	0	0	0	0	0	5	0				
	0	0	0	0	0	5	0				
16	0	0	0	0	0	5	0				
18	0	0	0	0	0	5	0				
20	0	0	0	0	0	5	0				
22	0	0	0	0	0	5	0				
24	0	0	0	0	0	5	0				
26	0	0	0	0	0	5	0				
28	0	0	0	0	0	5	0				
30	0	0	0	0	0	5	0				
32	0	0	0	0	0	5	0				
34	0	0	0	0	0	5	0				
36	0	0	0	0	0	5	0				
38	0	0	0	0	0	5	0				
40	0	0	0	0	0	5	0				
42	0	0	0	0	0	6	0				
44	0	0	0	0	0	6	0				
46	0	0	0	0	0	6	0				
48	0	0	0	0	0	6	0				
50	0	0	0	0	0	6	0				
52	0	0	0	0	0	6	0				
54	0	0	0	0	0	6	0				
56	0	0	0	0	0	7	0				
58	0	0	0	0	0	11	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 0
Preheater Deposit Code: 1
TDR Spun Deposit Rating: 7 at 56

DIESEL CONTROL AL-13630-F AT 232°C (450°F)—TEST 3*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	4	0				
04	0	0	0	0	0	4	0				
06	0	0	0	0	0	4	0				
08	0	0	0	0	0	4	0				
10	0	0	0	0	0	4	0				
12	0	0	0	0	0	4	0				
14	0	0	0	0	0	3	0				
16	0	0	0	0	0	3	0				
18	0	0	0	0	0	3	0				
20	0	0	0	0	0	3	0				
22	0	0	0	0	0	3	0				
24	0	0	0	0	0	3	0				
26	0	0	0	0	0	3	0				
28	0	0	0	0	0	4	0				
30	0	0	0	0	0	3	0				
32	0	0	0	0	0	4	0				
34	0	0	0	0	0	4	0				
36	0	0	0	0	0	4	0				
38	0	0	0	0	0	4	0				
40	0	0	0	0	0	4	0				
42	0	0	0	0	0	4	0				
44	0	0	0	0	0	4	0				
46	0	0	0	0	0	4	0				
48	0	0	0	0	0	4	0				
50	0	0	0	0	0	4	0				
52	0	0	0	0	0	4	0				
54	0	0	0	0	0	4	0				
56	0	0	0	0	0	4	0				
58	0	0	0	0	0	12	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 0
Preheater Deposit Code: 1
TDR Spun Deposit Rating: 4 at 54

DIESEL CONTROL AL-13630-F AT 260°C (500°F)—TEST 1*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	8	0				
04	0	0	0	0	0	5	0				
06	0	0	0	0	0	4	0				
08	0	0	0	0	0	4	0				
10	0	0	0	0	0	3	0				
12	0	0	0	0	0	3	0				
14	0	0	0	0	0	3	0				
16	0	0	0	0	0	3	0				
18	0	0	0	0	0	3	0				
20	0	0	0	0	0	4	0				
22	0	0	0	0	0	4	0				
24	0	0	0	0	0	4	0				
26	0	0	0	0	0	4	0				
28	0	0	0	0	0	4	0				
30	0	0	0	0	0	5	0				
32	0	0	0	0	0	6	0				
34	0	0	0	0	0	6	0				
36	0	0	0	0	0	7	0				
38	0	0	0	0	0	8	0				
40	0	0	0	0	0	8	0				
42	0	0	0	0	0	9	0				
44	0	0	0	0	0	8	0				
46	0	0	0	0	0	8	0				
48	0	0	0	0	0	8	0				
50	0	0	0	0	0	7	0				
52	0	0	0	0	0	6	0				
54	0	0	0	0	0	6	0				
56	0	0	0	0	0	[illegible]	0				
58	0	0	0	0	0	10	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 0
Preheater Deposit Code: 2
TDR Spun Deposit Rating: 8 at 46

DIESEL CONTROL AL-13630-F AT 260°C (500°F)—TEST 2*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	1	0				
04	0	0	0	0	0	0	0				
06	0	0	0	0	0	0	0				
08	0	0	0	0	0	0	0				
10	0	0	0	0	0	0	0				
12	0	0	0	0	0	0	0				
14	0	0	0	0	0	0	0				
16	0	0	0	0	0	0	0				
18	0	0	0	0	0	0	0				
20	0	0	0	0	0	0	0				
22	0	0	0	0	0	0	0				
24	0	0	0	0	0	0	0				
26	0	0	0	0	0	0	0				
28	0	0	0	0	0	0	0				
30	0	0	0	0	0	0	0				
32	0	0	0	0	0	1	0				
34	0	0	0	0	0	1	0				
36	0	0	0	0	0	3	0				
38	0	0	0	0	0	3	0				
40	0	0	0	0	0	4	0				
42	0	0	0	0	0	4	0				
44	0	0	0	0	0	4	0				
46	0	0	0	0	0	4	0				
48	0	0	0	0	0	3	0				
50	0	0	0	0	0	2	0				
52	0	0	0	0	0	2	0				
54	0	0	0	0	0	1	0				
56	0	0	0	0	0	2	0				
58	0	0	0	0	0	3	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 0
Preheater Deposit Code: >2
TDR Spun Deposit Rating: 4 at 44

DIESEL CONTROL AL-13630-F AT 260°C (500°F)—TEST 3*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	3	0				
04	0	0	0	0	0	4	0				
06	0	0	0	0	0	2	0				
08	0	0	0	0	0	1	0				
10	0	0	0	0	0	1	0				
12	0	0	0	0	0	1	0				
14	0	0	0	0	0	1	0				
16	0	0	0	0	0	1	0				
18	0	0	0	0	0	1	0				
20	0	0	0	0	0	1	0				
22	0	0	[illegible]	0	0	1	0				
24	0	0	0	0	0	1	0				
26	0	0	0	0	0	2	0				
28	0	0	0	0	0	2	0				
30	0	0	0	0	0	3	0				
32	0	0	0	0	0	4	0				
34	0	0	0	0	0	4	0				
36	0	0	0	0	0	3	0				
38	0	0	0	0	0	3	0				
40	0	0	0	0	0	6	0				
42	0	0	0	0	0	6	0				
44	0	0	0	0	0	6	0				
46	0	0	0	0	0	[illegible]	0				
48	0	0	0	0	0	3	0				
50	0	0	0	0	0	3	0				
52	0	0	0	0	0	3	0				
54	0	0	0	0	0	3	0				
56	0	0	0	0	0	[illegible]	0				
58	0	0	0	0	0	12	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 0
Preheater Deposit Code: >2
TDR Spun Deposit Rating: 6 at 42

DIESEL CONTROL AL-13630-F AT 268°C (515°F)—TEST 1*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	3	0				
04	0	0	0	0	0	3	0				
06	0	0	0	0	0	2	0				
08	0	0	0	0	0	2	0				
10	0	0	0	0	0	2	0				
12	0	0	0	0	0	2	0				
14	0	0	0	0	0	2	0				
16	0	0	0	0	0	3	0				
18	0	0	0	0	0	2	0				
20	0	0	0	0	0	3	0				
22	0	0	0	0	0	3	0				
24	0	0	0	0	0	3	0				
26	0	0	0	0	0	4	0				
28	0	0	0	0	0	5	0				
30	1.0	0	0	2.6	0.9	6	2				
32	0	5.3	1.4	1.5	2.1	8	2				
34	1.0	0	0	0	0.3	10	3				
36	2.6	2.9	3.8	0	2.3	12	3				
38	5.2	0	3.7	3.4	3.1	13	3				
40	3.2	3.7	0	1.8	2.2	15	3				
42	1.7	1.0	3.0	8.0	3.4	15	3				
44	12.5	6.0	2.5	1.0	5.5	14	3				
46	1.6	0	0	4.3	1.5	13	3				
48	2.4	3.9	0	2.2	2.1	11	3				
50	2.8	2.4	2.0	0	1.8	10	2				
52	2.0	3.0	0	4.3	2.3	9	2				
54	1.0	0	0	0	0.3	9	2				
56	0	0	0	0	0	10	2				
58	0	0	0	0	0	15	1				
TOTAL	37.0	28.2	16.4	29.1	27.8						

*JFTOT, D 3241
Change in Pressure Drop, mm. of Hg: 0
Preheater Deposit Code: 3
TDR Spun Deposit Rating: 15 at 42

DIESEL CONTROL AL-13630-F AT 268°C (515°F)—TEST 2*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	4	0				
04	0	0	0	0	0	3	0				
06	0	0	0	0	0	3	0				
08	0	0	0	0	0	3	0				
10	0	0	0	0	0	3	0				
12	0	0	0	0	0	3	0				
14	0	0	0	0	0	[illegible]	0				
16	0	0	0	0	0	3	0				
18	0	0	0	0	0	3	0				
20	0	0	0	0	0	3	0				
22	0	0	0	0	0	3	0				
24	0	0	0	0	0	4	0				
26	0	0	0	0	0	4	0				
28	0	0	0	0	0	5	0				
30	0	0	0	0	0	6	0				
32	0	0	0	0	0	7	0				
34	0	0	0	0	0	8	2				
36	0	0	0	0	0	11	2				
38	0	0	0	0	0	13	3				
40	0	0	0	0	0	14	3				
42	0	0	0	0	[illegible]	15	3				
44	0	0	0	0	0	14	3				
46	0	0	0	0	0	13	3				
48	0	0	0	0	0	10	3				
50	0	0	0	0	0	9	2				
52	0	0	0	0	0	8	2				
54	0	0	0	0	0	7	2				
56	0	0	0	0	0	8	2				
58	0	0	0	0	0	15	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 0
Preheater Deposit Code: 3
TDR Spun Deposit Rating: 15 at 42

DIESEL CONTROL AL-13630-F AT 268°C (515°F)—TEST 3*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	2	0				
04	0	0	0	0	0	1	0				
06	0	0	0	0	0	1	0				
08	0	0	0	0	0	0	0				
10	0	0	0	0	0	3	0				
12	0	0	0	0	0	0	0				
14	0	0	0	0	0	0	0				
16	0	0	0	0	0	0	0				
18	0	0	0	0	0	0	0				
20	0	0	0	0	0	1	0				
22	0	0	0	0	0	1	0				
24	0	0	0	0	0	1	0				
26	0	0	0	0	0	2	0				
28	0	0	0	0	0	2	0				
30	0	0	0	0	0	3	0				
32	0	0	0	0	0	4	0				
34	0	0	0	0	0	5	2				
36	0	0	0	0	0	7	2				
38	0	0	0	0	0	9	3				
40	0	0	0	0	0	10	3				
42	0	0	0	0	0	11	3				
44	0	0	0	0	0	11	3				
46	0	0	0	0	0	10	3				
48	0	0	0	0	0	8	3				
50	0	0	0	0	0	6	2				
52	0	0	0	0	0	5	2				
54	0	0	0	0	0	5	2				
56	0	0	0	0	0	6	0				
58	0	0	0	0	0	14	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 0
Preheater Deposit Code: 3
TDR Spun Deposit Rating: 11 at 44

DIESEL CONTROL AL-13630-F AT 274°C (525°F)—TEST 1*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	5	0				
04	0	0	0	0	0	5	0				
06	0	0	0	0	0	4	0				
08	0	0	0	0	0	4	0				
10	0	0	0	0	0	[illegible]	0				
12	0	0	0	0	0	4	0				
14	0	0	0	0	0	4	0				
16	0	0	0	0	0	3	0				
18	0	0	0	0	0	4	0				
20	0	0	0	0	0	4	0				
22	0	0	0	0	0	4	0				
24	0	0	0	0	0	4	0				
26	0	0	0	0	0	5	0				
28	0	0	0	0	0	7	0				
30	0	0	0	0	0	8	0				
32	2.1	0	3.5	5.0	2.5	10	2				
34	3.6	4.3	4.7	0	3.2	14	3				
36	5.7	4.1	4.6	8.9	5.8	18	4				
38	[illegible]	0	17.7	10.7	8.4	22	4				
40	0	0	9.0	3.0	3.0	23	4				
42	6	[illegible]	0	2.5	3.3	23	4				
44	5.0	3.8	5.1	4.3	4.6	23	4				
46	27.3	0	6.3	27.0	16.0	23	4				
48	0	2.0	18.9	5.0	5	21	4				
50	0	0	13.0	4.5	4.8	18	3				
52	0	0	6.0	4.7	2.7	16	1				
54	0	4.0	0	5.0	2.3	13	2				
56	0	[illegible]	0	0	1.0	13	0				
58	[illegible]	4.5	0	0	2.3	16	3				
TOTAL	[illegible]	56.3	[illegible]	68.3	[illegible]						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 1 at 150 min
Preheater Deposit Code: >3
TDR Spun Deposit Rating: 23 at 44

DIESEL CONTROL AL-13630-F AT 274°C (525°F)—TEST 2*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	7	0				
04	0	0	0	0	0	7	0				
06	0	0	0	0	0	6	0				
08	0	0	0	0	0	5	0				
10	0	0	0	0	0	4	0				
12	0	0	0	0	0	4	0				
14	0	0	0	0	0	4	0				
16	0	0	0	0	0	4	0				
18	0	0	0	0	0	4	0				
20	0	0	0	0	0	5	0				
22	0	0	0	0	0	5	0				
24	0	0	0	0	0	6	0				
26	0	0	0	0	0	7	0				
28	0	0	0	0	0	8	0				
30	0	0	0	0	0	10	0				
32	0	0	0	0	0	12	0				
34	0	0	0	0	0	15	2				
36	2.0	0	8.5	2.9	3.4	19	3				
38	3.6	7.6	3.3	5.3	5.0	21	3				
40	3.6	11.0	0	14.2	7.2	22	3				
42	0	3.0	4.0	2.0	2.3	22	3				
44	0	31.9	2.0	20.9	13.7	22	3				
46	0	6.7	1.4	4.3	3.1	22	3				
48	3.5	0	0	10.0	3.4	19	3				
50	1.9	14.0	2.8	4.1	5.7	16	4				
52	0	2.0	2.9	2.1	1.8	13	3				
54	0	0	1.0	0	0.3	13	2				
56	0	0	0	0	0	13	2				
58	0	0	0	0	0	16	0				
TOTAL	14.6	76.2	25.9	65.8	45.9						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 1 at 150 min
Preheater Deposit Code: >3
TDR Spun Deposit Rating: 22 at 44

DIESEL CONTROL AL-13630-F AT 274°C (525°F)—TEST 3*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	2	0				
04	0	0	0	0	0	2	0				
06	0	0	0	0	0	1	0				
08	0	0	0	0	0	1	0				
10	0	0	0	0	0	1	0				
12	0	0	0	0	0	1	0				
14	0	0	0	0	0	1	0				
16	0	0	0	0	0	1	0				
18	0	0	0	0	0	2	0				
20	0	0	0	0	0	2	0				
22	0	0	0	0	0	2	0				
24	0	0	0	0	0	2	0				
26	0	0	0	0	0	3	0				
28	0	0	0	0	0	3	0				
30	0	0	0	0	0	6	0				
32	0	0	0	0	0	9	0				
34	0	0	0	0	0	12	2				
36	0	0	0	0	0	16	3				
38	7.6	1.0	0	0	2.2	19	4				
40	3.7	4.0	3.0	12.2	5.7	21	4				
42	10.0	0	0	0	2.5	22	4				
44	3.9	0	0	2.9	1.7	21	4				
46	8.1	0	4.7	3.5	4.1	20	4				
48	1.9	0	5.4	0	1.8	17	4				
50	2.9	3.0	1.0	0	1.7	14	3				
52	13.6	1.0	0	5.0	4.9	11	2				
54	0	0	0	0	0	10	2				
56	0	0	0	1.9	0.5	11	1				
58	0	0	0	0	0	10	0				
TOTAL	53.7	9.0	19.1	23.5	23.1						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 1 at 150 min
Preheater Deposit Code: >3
TDR Spun Deposit Rating: 22 at 42

DIESEL CONTROL AL-13630-F AT 288°C (550°F)—TEST 1*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 5 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	4	0				
04	0	0	0	0	0	4	0				
06	0	0	0	0	0	4	0				
08	0	0	0	0	0	5	0				
10	0	0	0	0	0	4	0				
12	0	0	0	0	0	4	0				
14	0	0	0	0	0	3	0				
16	0	0	0	0	0	2	0				
18	0	0	0	0	0	2	0				
20	0	0	0	0	0	2	0				
22	0	0	0	0	0	2	0				
24	0	0	0	0	0	3	0				
26	0	0	0	0	0	4	0				
28	0	0	0	0	0	8	0				
30	0	1.0	0	0	0.3	13	2				
32	2.7	4.9	0	3.1	2.7	20	3				
34	0	5.4	0	5.4	2.7	21	4				
36	34.8	2.0	16.6	5.9	14.8	21	4				
38	53.3	69.0	24.5	4.2	37.8	31	3				
40	46.8	80.0	49.9	39.5	54.1	35	4				
42	6.0	94.2	3.0	40.5	35.9	38	4				
44	82.4	80.7	44.6	6.2	53.4	38	4				
46	36.6	67.9	90.8	5.0	50.0	37	4				
48	4.7	77.6	66.6	21.1	42.5	26	4				
50	24.0	56.5	57.6	0	34.5	13	3				
52	3.0	0	2.0	33.6	9.7	10	0				
54	12.0	25.0	5.1	36.5	19.7	10	0				
56	0	0	2.1	5.0	1.8	11	0				
58	3.0	5.3	1.0	0	2.3	26	4				
TOTAL	309.3	569.5	363.6	206.0	362.2						

*JFTOT, D 3241

Change in Pressure Drop, mm of Hg: 1 at 150 min
Preheater Deposit Code: 4
TDR Spun Deposit Rating: 38 at 44

DIESEL CONTROL AL-13630-F AT 288°C (550°F)—TEST 2*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 5 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	4	0				
04	0	0	0	0	0	4	0				
06	0	0	0	0	0	3	0				
08	0	0	0	0	0	3	0				
10	0	0	0	0	0	3	0				
12	0	0	0	0	0	3	0				
14	0	0	0	0	0	3	0				
16	0	0	0	0	0	3	0				
18	0	0	0	0	0	3	0				
20	0	0	0	0	0	4	0				
22	0	0	0	0	0	4	0				
24	0	0	0	0	0	6	0				
26	0	0	0	0	0	8	0				
28	0	0	0	0	0	13	2				
30	0	3.0	0	2.3	1.3	18	3				
32	1.0	[illegible]	1.0	2.6	2.1	21	4				
34	4.0	30.7	3.4	25.9	16.0	19	4				
36	7.8	3.9	0	13.2	6.2	20	4				
38	12.7	25.4	13.3	39.4	22.8	30	3				
40	64.2	29.5	12.9	42.0	35.4	36	4				
42	71.9	67.6	89.5	71.0	75.0	37	4				
44	83.[illegible]	101.9	63.2	36.0	71.3	38	4				
46	32.4	94.8	43.1	44.3	58.7	34	4				
48	11.5	0	30.0	3.7	11.3	22	4				
50	3.0	32.8	5.9	6.2	13.5	17	3				
52	0	0	6.0	51.5	14.4	10	0				
54	2.6	0	1.0	7.1	2.7	11	0				
56	6.7	0	0	0	1.2	12	0				
58	3.8	5.5	10.0	11.4	8.1	30	4				
TOTAL	329.5	393.3	329.6	356.6	340.0						

*JFTOT, D 3241

Change in Pressure Drop, mm of Hg: 1 at 150 min
Preheater Deposit Code: 4
TDR Spun Deposit Rating: 38 at 44

DIESEL CONTROL AL-13630-F AT 288°C (550°F)—TEST 3*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	4	0				
04	0	0	0	0	0	2	0				
06	0	0	0	0	0	2	0				
08	0	0	0	0	0	1	0				
10	0	0	0	0	0	1	0				
12	0	0	0	0	0	1	0				
14	0	0	0	0	0	1	0				
16	0	0	0	0	0	1	0				
18	0	0	0	0	0	1	0				
20	0	0	0	0	0	2	0				
22	0	0	0	0	0	2	0				
24	0	0	0	0	0	2	0				
26	0	0	0	0	0	4	0				
28	0	0	0	0	0	6	2				
30	0	1.0	0	0	0.3	19	3				
32	3.1	25.0	5.2	8.7	10.5	21	4				
34	5.2	5.2	0	26.3	9.2	18	4				
36	38.3	38.9	13.5	9.9	25.2	21	4				
38	52.2	51.4	12.1	44.5	40.1	31	3				
40	73.6	47.4	4.2	53.9	44.8	37	4				
42	74.0	56.4	62.8	51.3	61.1	38	4				
44	56.1	43.7	105.3	45.7	62.7	38	4	0.2 µm		0.2-0.3 µm	
46	82.5	39.6	58.3	71.3	62.9	35	4				
48	5.9	47.8	48.3	48.9	37.7	20	4				
50	18.0	5.6	32.2	26.4	20.6	11	3				
52	3.0	28.0	12.8	5.7	12.4	9	2				
54	3.0	3.6	5.3	0	3.0	9	0				
56	2.0	4.2	7.1	3.0	4.1	10	0				
58	20.0	85.2	93.1	6.0	51.1	35	0				
TOTAL	436.9	483.0	460.2	401.6	445.7						

*JFTOT, D 3241

Change in Pressure Drop, mm of Hg: 1 at 150 min
Preheater Deposit Code: 4
TDR Spun Deposit Rating: 38 at 44

JET A-1 AL-13623-T AT 260°C (500°F)—TEST 522T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	12	0				
04	0	0	0	0	0	9	0				
06	0	0	0	0	0	9	0				
08	0	0	0	0	0	9	0				
10	0	0	0	0	0	9	0				
12	0	0	0	0	0	9	0				
14	0	0	0	0	0	9	0				
16	0	0	0	0	0	9	0				
18	0	0	0	0	0	9	0				
20	0	0	0	0	0	9	0				
22	0	0	0	0	0	9	0				
24	0	0	0	0	0	9	0				
26	0	0	0	0	0	9	0				
28	0	0	0	0	0	9	0				
30	0	0	0	0	0	10	0				
32	0	0	0	0	0	10	0				
34	0	0	0	0	0	10	0				
36	0	0	0	0	0	10	0				
38	0	0	0	0	0	10	0				
40	0	0	0	0	0	10	0				
42	0	0	0	0	0	10	0				
44	0	0	2.8	0	0.7	9	0				
46	0	0	0	0	0	10	0				
48	0	0	0	0	0	9	0				
50	0	0	0	0	0	9	0				
52	0	0	0	0	0	9	0				
54	0	0	0	0	0	8	0				
56	0	0	0	0	0	9	0				
58	0	0	0	0	0	13	0				
TOTAL	0	0	2.8	0	0.7						

*JFTOT, D 3241

Change in Pressure Drop, mm of Hg: 35 at 150 min
Preheater Deposit Code: 1
TDR Spun Deposit Rating: 10 at 40

JET A-1 AL-13623-T AT 260°C (500°F)—TEST 525T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	8	0				
04	0	0	0	0	0	7	0				
06	0	0	0	0	0	8	0				
08	0	0	0	0	0	7	0				
10	0	0	0	0	0	7	0				
12	0	0	0	0	0	7	0				
14	0	0	0	0	0	7	0				
16	0	0	0	0	0	7	0				
18	0	0	0	0	0	7	0				
20	0	0	0	0	0	7	0				
22	0	0	0	0	0	7	0				
24	0	0	0	0	0	7	0				
26	0	0	0	0	0	7	0				
28	0	0	0	0	0	8	0				
30	0	0	0	0	0	8	0				
32	0	0	0	0	0	8	0				
34	0	0	0	0	0	8	0				
36	0	0	0	0	0	9	0				
38	0	0	0	0	0	9	0				
40	0	0	0	0	0	9	0				
42	0	0	0	0	0	9	0				
44	0	0	0	0	0	8	0				
46	0	0	0	0	0	8	0				
48	0	0	0	0	0	9	0				
50	0	0	0	0	0	9	0				
52	0	0	0	0	0	9	0				
54	0	0	0	0	0	9	0				
56	0	0	0	0	0	9	0				
58	0	0	0	0	0	12	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241

Change in Pressure Drop, mm of Hg: 3 at 150 min
Preheater Deposit Code: 1
TDR Spun Deposit Rating: 9 at 40

JET A-1 AL-13623-T AT 260°C (500°F)—TEST 527J*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	$\bar{x}$ - Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	1	0				
04	0	0	0	0	0	1	0				
06	0	0	0	0	0	1	0				
08	0	0	0	0	0	1	0				
10	0	0	0	0	0	1	0				
12	0	0	0	0	0	1	0				
14	0	0	0	0	0	0	0				
16	0	0	0	0	0	0	0				
18	0	0	0	0	0	1	0				
20	0	0	0	0	0	1	0				
22	0	0	0	0	0	0	0				
24	0	0	0	0	0	1	0				
26	0	0	0	0	0	1	0				
28	0	0	0	0	0	1	0				
30	0	0	0	0	0	1	0				
32	0	0	0	0	0	1	0				
34	0	0	0	0	0	1	0				
36	0	0	0	0	0	1	0				
38	0	0	0	0	0	2	0				
40	0	0	0	0	0	2	0				
42	0	0	0	0	0	2	0				
44	0	0	0	0	0	1	0				
46	0	0	0	0	0	1	0				
48	0	0	0	0	0	1	0				
50	0	0	0	0	0	1	0				
52	0	0	0	0	0	1	0				
54	0	0	0	0	0	1	0				
56	0	0	0	0	0	2	0				
58	0	0	0	0	0	12	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 1 at 150 min
Preheater Deposit Code: 1
TDR Spun Deposit Rating: 2 at 40

JET A-1 AL-13623-T AT 274°C (525°F)—TEST 529J*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	0	0				
04	0	0	0	0	0	0	0				
06	0	0	0	0	0	0	0				
08	0	0	0	0	0	0	0				
10	0	0	0	0	0	0	0				
12	0	0	0	0	0	0	0				
14	0	0	0	0	0	1	0				
16	0	0	0	0	0	0	0				
18	0	0	0	0	0	0	0				
20	0	0	0	0	0	0	0				
22	0	0	0	0	0	0	0				
24	0	0	0	0	0	0	0				
26	0	0	0	0	[illegible]	0	0				
28	0	0	0	0	0	0	0				
30	0	0	0	0	0	0	0				
32	0	[illegible]	0	0	0	0	0				
34	0	[illegible]	0	0	0	0	0				
36	0	0	0	[illegible]	0	0	[illegible]				
38	0	0	[illegible]	0	0	0	0				
40	0	[illegible]	[illegible]	0	0	0	0				
42	0	[illegible]	[illegible]	[illegible]	0	1	0				
44	0	[illegible]	[illegible]	0	0	1	0				
46	0	0		0	[illegible]	2	0				
48	0	0	0	[illegible]	[illegible]	1	[illegible]				
50	0	0	[illegible]	0	0	[illegible]					
52	0	0	0	0	0	0	[illegible]				
54	0	0	0	[illegible]	0	[illegible]	[illegible]				
56	0	0	0	0	0	0	[illegible]				
58	0	0	[illegible]	0	[illegible]	4	[illegible]				
TOTAL	0	0	0	0	[illegible]						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 13 at 150 min
Preheater Deposit Code: 2
TDR Spun Deposit Rating: 2 at 46

JET A-1 AL-13623-T AT 274°C (525°F)--TEST 530T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	1	0				
04	0	0	0	0	0	0	0				
06	0	0	0	0	0	0	0				
08	0	0	0	0	0	0	0				
10	0	0	0	0	0	0	0				
12	0	0	0	0	0	0	0				
14	0	0	0	0	0	0	0				
16	0	0	0	0	0	0	0				
18	0	0	0	0	0	0	0				
20	0	0	0	0	0	0	0				
22	0	0	0	0	0	0	0				
24	0	0	0	0	0	0	0				
26	0	0	0	0	0	0	0				
28	0	0	0	0	0	0	0				
30	0	0	0	0	0	1	0				
32	0	0	0	0	0	1	0				
34	0	0	0	0	0	1	0				
36	0	0	0	0	0	1	0				
38	0	0	0	0	0	2	0				
40	0	0	0	0	0	1	0				
42	0	0	0	0	0	2	0				
44	0	0	0	0	0	2	0				
46	0	0	0	0	0	2	0				
48	0	0	0	0	0	2	0				
50	0	0	0	0	0	1	0				
52	0	0	0	0	0	0	0				
54	0	0	0	0	0	0	0				
56	0	0	0	0	0	0	0				
58	0	0	0	0	0	2	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 95 min
Preheater Deposit Code: >1
TDR Spun Deposit Rating: 2 at 44

JET A-1 AL-13623-T AT 274°C (525°F)--TEST 5373*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	0	0				
04	0	0	0	0	0	0	0				
06	0	0	0	0	0	0	0				
08	0	0	0	0	[illegible]	0	0				
10	0	0	0	0	0	0	0				
12	0	0	0	0	0	0	0				
14	0	0	0	0	0	0	0				
16	0	0	0	0	0	0	0				
18	0	0	0	0	0	0	0				
20	0	0	[illegible]	0	0	0	0				
22	0	0	0	0	0	0	0				
24	0	0	0	0	0	0	0				
26	0	0	0	0	0	0	0				
28	0	0	0	0	0	0	0				
30	0	0	0	0	0	0	0				
32	0	1	0	0	0	0	0				
34	0	0	0	0	0	0	0				
36	0	0	0	[illegible]	0	0	0				
38	0	0	0	0	0	1	0				
40	0	0	0	0	0		0				
42	0	0	0	0	0	1	[illegible]				
44	0	0	0	0	0	1	0				
46	[illegible]	0	0	0	0	1	0				
48	0	0	0	0	[illegible]	1	[illegible]				
50	0	0	0	0	0	1	[illegible]				
52	0	0	0	0	0	0	0				
54	0	0	0	0	0	0	0				
56	0	0	0	0	0	0	0				
58	0	0	0	0	0	1	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 145 min
Preheater Deposit Code: 1
TDR Spun Deposit Rating: 1 at 44

JET A-1 AL-13623-T AT 281°C (538°F)—TEST 531J*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	0	0				
04	0	0	0	0	0	0	0				
06	0	0	0	0	0	0	0				
08	0	0	0	0	0	0	0				
10	0	0	0	0	0	0	0				
12	0	0	0	0	0	-1	0				
14	0	0	0	0	0	-1	0				
16	0	0	0	0	0	-1	0				
18	0	0	0	0	0	-1	0				
20	0	0	0	0	0	-1	0				
22	0	0	0	0	0	-1	0				
24	0	0	0	0	0	0	0				
26	0	0	0	0	0	0	0				
28	0	0	0	0	0	0	0				
30	0	0	0	0	0	0	0				
32	0	0	0	0	0	0	0				
34	0	0	0	0	0	1	0				
36	0	0	0	0	0	3	1				
38	0	0	0	0	0	5	[illegible]				
40	0	0	0	3.6	0.9	8	2				
42	0	0	1.6	0	0.4	10	3				
44	2.5	0	0	0	0.6	10	3				
46	2.5	7.9	4.5	0	3.7	9	3				
48	0	0	0	0	0	6	2				
50	2.2	7.0	2.3	0	2.9	[illegible]	1				
52	0	0	0	0	0	1	0				
54	0	0	0	0	0	0	0				
56	0	0	0	0	0	0	0				
58	0	0	0	0	0	3	0				
TOTAL	7.2	16.9	8.5	3.6	8.5						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 2 at 150 min
Preheater Deposit Code: >3
TDR Spun Deposit Rating: 10 at 44

JET A-1 AL-13623-T AT 281°C (538°F)—TEST 532T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	2	0				
04	0	0	0	0	0	0	0				
06	0	0	0	0	0	0	0				
08	0	0	0	0	0	0	0				
10	0	0	0	0	0	1	0				
12	0	0	0	0	0	1	0				
14	0	0	0	0	0	1	0				
16	0	0	0	0	0	1	0				
18	0	0	0	0	0	1	0				
20	0	0	0	0	0	1	0				
22	0	0	0	0	0	1	0				
24	0	0	0	0	0	1	0				
26	0	0	0	0	0	1	0				
28	0	0	0	0	0	1	0				
30	0	0	0	0	0	0	0				
32	0	0	0	0	0	0	0				
34	0	0	0	0	0	0	0				
36	0	0	0	0	0	0	0				
38	0	0	0	0	0	0	0				
40	0		0	0	0	0	0				
42	[illegible]		0	0	[illegible]	1	1				
44	[illegible]	[illegible]	0	0	0	[illegible]	1				
46	0	[illegible]	0	0	0	[illegible]	1				
48	0	[illegible]	[illegible]	[illegible]	[illegible]	2	1				
50	[illegible]	0	[illegible]	0	[illegible]	1	0				
52	0	0	0	[illegible]	[illegible]	0	0				
54	0	0	0	0	0	0	1				
56	0	0	0	0	0	1	[illegible]				
58	0	0	0	0	0	[illegible]	[illegible]				
TOTAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 57 at 150 min
Preheater Deposit Code: 2
TDR Spun Deposit Rating: 3 at 44

JET A-1 AL-13623-T AT 281°C (538°F)—TEST 533J*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	0	0				
04	0	0	0	0	0	0	0				
06	0	0	0	0	0	0	0				
08	0	0	0	0	0	0	0				
10	0	0	0	0	0	0	0				
12	0	0	0	0	0	0	0				
14	0	0	0	0	0	0	0				
16	0	0	0	0	0	0	0				
18	0	0	0	0	0	0	0				
20	0	0	0	0	0	0	0				
22	0	0	0	0	0	0	0				
24	0	0	0	0	0	0	0				
26	0	0	0	0	0	0	0				
28	0	0	0	0	0	0	0				
30	0	0	0	0	0	1	0				
32	0	0	0	0	0	1	0				
34	0	0	0	0	0	2	0				
36	0	0	0	0	0	2	0				
38	0	0	0	0	0	2	0				
40	0	0	0	0	0	3	0				
42	0	0	0	0	0	5	1				
44	0	2.5	0	0	0.6	7	1				
46	0	0	0	0	0	7	1				
48	2.7	0	0	1.2	1.0	5	1				
50	0	0	3.2	0	0.8	4	1				
52	0	0	0	0	0	2	0				
54	0	0	0	0	0	2	0				
56	0	0	0	0	0	2	0				
58	0	0	0	0	0	3	0				
TOTAL	2.7	2.5	3.2	1.2	2.4						

*JFTOT, D 3241
- Change in Pressure Drop, mm of Hg: 6 at 150 min
- Preheater Deposit Code: 2
- TDR Spun Deposit Rating: 7 at 46

JET A-1 AL-13623-T AT 288°C (550°F)—TEST 526T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	6	0				
04	0	0	0	0	0	4	0				
06	0	0	0	0	0	5	0				
08	0	0	0	0	0	5	0				
10	0	0	0	0	0	2	0				
12	0	0	0	0	0	1	0				
14	0	0	0	0	0	0	0				
16	0	0	0	0	0	0	0				
18	0	0	0	0	0	0	0				
20	0	0	0	0	0	0	0				
22	0	0	0	0	0	0	0				
24	0	0	0	0	0	1	0				
26	0	0	0	0	0	0	0				
28	0	0	0	0	0	0	0				
30	0	0	0	0	[illegible]	1	0				
32	0	0	0	0	0	1	0				
34	0	0	0	0	0	1	0				
36	0	0	0	0	0	1	0				
38	0	0	0	0	0	5	0				
40	0	2.0	2.0	5.0	2.3	12	2				
42	6.5	2.8	0	11.5	5.2	10	4				
44	1.9	[illegible]	3.5	5.3	2.1	6	4				
46	9.0	2.4	[illegible]	2.5	4.2	6	4				
48	5.1	[illegible]	[illegible]	1.8	[illegible]	9	4				
50	[illegible]	0	0	0	0	9	4				
52	0	0	0	0	0	5	3				
54	0	0	0	0	0	4	3				
56	0	0	0	0	0	2	1				
58	0	0	0	0	[illegible]	6	1				
TOTAL	22.3	[illegible]	[illegible]	[illegible]	[illegible]						

*JFTOT, D 3241
- Change in Pressure Drop, mm of Hg: 125 at 142 min
- Preheater Deposit Code: [illegible]4
- TDR Spun Deposit Rating: 12 at 40

JET A-1 AL-13623-T AT 288°C (550°F)—TEST 528T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	0	0				
04	0	0	0	0	0	0	0				
06	0	0	0	0	0	0	0				
08	0	0	0	0	0	0	0				
10	0	0	0	0	0	0	0				
12	0	0	0	0	0	0	0				
14	0	0	0	0	0	0	0				
16	0	0	0	0	0	0	0				
18	0	0	0	0	0	0	0				
20	0	0	0	0	0	0	0				
22	0	0	0	0	0	0	0				
24	0	0	0	0	0	0	0				
26	0	0	0	0	0	0	0				
28	0	0	0	0	0	0	0				
30	0	0	0	0	0	1	0				
32	0	0	0	0	0	1	0				
34	0	0	0	0	0	1	0				
36	0	0	0	0	0	4	0				
38	0	0	0	0	0	11	0				
40	0	1.0	0	0	0.3	11	2				
42	0	6.5	2.5	0	2.3	6	4				
44	13.7	0	19.9	0	8.4	4	4				
46	2.0	1.0	25.9	11.7	10.2	6	4				
48	26.0	2.0	2.5	2.2	8.2	10	4				
50	1.8	1.6	1.5	3.3	2.1	8	4				
52	0	5.0	0	0	1.3	5	4				
54	0	[illegible]	0	4.1	1.0	2	3				
56	0	0	0	0	0	0	2				
58	0	2.0	0	0	0.5	4	0				
TOTAL	43.5	19.1	52.3	21.3	34.1						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 133 min
Preheater Deposit Code: >4
TDR Spur Deposit Rating: 10 at 48

JET A-1 AL-13623 [illegible] 288°C (550°F)—TEST 538T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	0	0				
04	0	0	0	0	0	0	[illegible]				
06	0	0	0	[illegible]	0	0	[illegible]				
08	0	0	[illegible]	0	0	0	[illegible]				
10	0	0	0	0	0	0	[illegible]				
12	0	0	[illegible]	[illegible]	0	0	0				
14	0	0	0	[illegible]	0	0	[illegible]				
16	0	0	0	0	0	0	[illegible]				
18	0	0	0	[illegible]	0	0	[illegible]				
20	0	0	0	0	0	0	[illegible]				
22	0	[illegible]	0	[illegible]	0	[illegible]	0				
24	0	0	0	[illegible]	0	0	0				
26	[illegible]	0	0	[illegible]	[illegible]	[illegible]	[illegible]				
28	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]				
30	[illegible]	0	0	[illegible]	[illegible]	1	[illegible]				
32	0	[illegible]	0	[illegible]	0	1	0				
34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]				
36	0	[illegible]	[illegible]	[illegible]	[illegible]	2	0				
38	0	[illegible]	[illegible]	[illegible]	[illegible]	5	1				
40	0	[illegible]	[illegible]	[illegible]	[illegible]	12	2				
42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6	4				
44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4				
46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4				
48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10	4				
50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11	4				
52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	[illegible]				
56	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	1				
58	0	[illegible]	[illegible]	[illegible]	[illegible]	4	[illegible]				
TOTAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 118 at [illegible] min
Preheater Deposit Code: [illegible]
TDR Spun Deposit Rating: 12 at [illegible]

JET A-1 AL-13623-T AT 302°C (575°F)—TEST 534T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	0	0				
04	0	0	0	0	0	-1	0				
06	0	0	0	0	0	-2	0				
08	0	0	0	0	0	-2	0				
10	0	0	0	0	0	-2	0				
12	0	0	2.0	0	0.5	-2	0				
14	0	0	0	0	0	-2	0				
16	0	0	0	0	0	-2	0				
18	0	0	0	0	0	-1	0				
20	0	0	0	0	0	-1	0				
22	0	0	0	0	0	0	0				
24	0	0	0	0	0	0	0				
26	0	0	0	0	0	0	0				
28	0	0	0	0	0	0	0				
30	0	0	0	0	0	0	0				
32	6.4	0	0	25.2	7.9	6	2				
34	2.1	0	5.9	33.0	10.3	17	4				
36	32.6	104.0	97.8	109.4	86.0	22	4				
38	141.2	202.6	153.6	160.3	164.4	28	4				
40	151.4	233.9	196.5	184.7	191.6	30	4				
42	218.7	231.8	211.1	191.3	213.2	32	4				
44	194.4	45.9	200.2	155.5	149.0	30	4				
46	167.6	137.0	192.4	143.8	165.2	25	4				
48	144.0	180.6	156.3	139.5	155.1	18	4				
50	103.3	60.6	74.4	54.0	73.1	11	3				
52	59.1	6.0	11.6	28.2	26.2	4	3				
54	20.9	38.4	0	7.4	16.7	6	4				
56	6.1	9.0	0	2.0	13.0	1	4				
58	3.5	0	0	0	1.4	7	0				
TOTAL	1252.9	1269.5	1301.8	1174.3	1258.1						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 99 min
Preheater Deposit Code: >4
TDR Spun Deposit Rating: 32 at 42

JET A-1 AL-13623-T AT 302°C (575°F)—TEST 535T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	1.9	0	0	0	0.5	0	0				
04	2.5	0	0	0	0.6	0	0				
06	3.0	0	0	0	0.8	0	0				
08	0	0	0	0	0	0	0				
10	0	2.0	2.9	0	1.2	0	0				
12	0	0	0	0	0	0	0				
14	0	0	0	0	0	0	0				
16	1.9	0	0	0	0.5	0	0				
18	2.0	0	0	0	0.5	0	0				
20	0	0	0	0	0	0	0				
22	0	0	0	0	0	1	0				
24	2.5	0	0	0	0.6	1	0				
26	0	0	0	0	0	1	0				
28	0	0	0	0	0	3	0				
30	4.4	0	0	0	1.1	3	0				
32	0	2.0	0	0	0.5	9	2				
34	13.2	11.0	0	0	6.1	15	>4 (P)				
36	7.7	55.5	62.6	59.4	46.3	19	>4 (P)				
38	104.0	150.3	98.0	106.5	114.7	23	4				
40	144.2	95.8	131.5	147.8	129.8	28	4				
42	143.6	181.8	169.5	198.8	173.4	29	4				
44	179.6	175.8	115.0	150.4	155.8	30	4				
46	105.5	102.0	83.8	200.0	122.8	25	4				
48	172.6	11.1	117.0	100.0	100.2	23	4				
50	7.0	25.8	69.1	99.4	48.8	17	3				
52	3.9	6.0	7.8	70.3	22.0	10	3				
54	7.1	30.0	2.9	3.6	10.9	9	4				
56	0	10.0	0	20.0	7.5	7	4				
58	0	5.5	0	0	1.4	10	2				
TOTAL	906.4	864.8	856.9	1135.8	944.0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 91 min
Preheater Deposit Code: >4
TDR Spun Deposit Rating: 30 at 44

JET A-1 AL-13623-T AT 302°C (575°F)—TEST 536J*

Tube Station	Dielectric Strength, Volts					MARK 9 TDR	Visual Rating	Thickness Measurement			
	0°	90°	180°	270°	Dielectric Average			0°	90°	180°	270°
02	0	0	0	0	0	-1	0				
04	0	0	0	0	0	-2	0				
06	0	0	0	0	0	-2	0				
08	0	0	0	0	0	-2	0				
10	0	0	0	0	0	-2	0				
12	0	0	0	0	0	-2	0				
14	0	0	0	0	0	-2	0				
16	0	0	0	0	0	-2	0				
18	0	0	0	0	0	-2	0				
20	0	0	0	0	0	-2	0				
22	0	1.9	0	0	0.5	-1	0				
24	0	0	0	0	0	-1	0				
26	0	0	0	0	0	0	0				
28	0	0	0	0	0	0	0				
30	15.1	0	0	0	3.8	1	0				
32	51.4	0	0	0	12.9	1	>4 (P)				
34	55.2	43.4	0	51.3	37.5	7	>4 (P)				
36	99.9	77.3	30.8	94.1	75.5	14	>4 (P)				
38	104.5	143.1	95.9	140.4	122.2	20	4				
40	156.4	157.6	104.0	182.5	150.1	28	4	0.4 μm			
42	104.3	203.9	254.7	202.0	151.2	32	4		0.8 μm		
44	81.2	147.7	220.6	158.8	152.1	34	4				0.7 μm
46	51.9	106.3	150.4	135.6	111.1	34	4				
48	28.5	80.4	150.7	62.6	80.6	25	4				
50	20.1	54.7	16.0	45.9	34.2	22	4				
52	25.2	10.5	48.2	5.5	22.4	16	3				
54	18.2	10.1	1.6	0	7.5	11	3				
56	5.4	2.3	7.5	0	3.8	8	2				
58	5.7	0	0	0	1.4	3	2				
TOTAL	769.6	1046.2	1080.6	1078.7	1006.8						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 98 min
Preheater Deposit Code: >4
TDR Spun Deposit Rating: 34 at 44

JET A-1 WITH TETRALIN (5%) AL-13633-T AT 246°C (475°F)—TEST 549J*

Tube Station	Dielectric Strength, Volts					MARK 9 TDR	Visual Rating	Thickness Measurement			
	0°	90°	180°	270°	Dielectric Average			0°	90°	180°	270°
02	0	0	0	0	0	4	0				
04	0	0	0	0	0	2	0				
06	0	0	0	0	0	2	0				
08	0	0	0	0	0	1	0				
10	0	0	0	0	0	1	0				
12	0	0	0	0	0	1	0				
14	0	0	0	0	0	1	0				
16	0	0	0	0	0	1	0				
18	0	0	0	0	0	1	0				
20	0	0	0	0	0	1	0				
22	0	0	0	0	0	1	0				
24	0	0	0	0	0	1	0				
26	0	0	0	0	0	1	0				
28	0	0	0	0	0	1	0				
30	0	0	0	0	0	1	0				
32	0	0	0	0	0	1	0				
34	0	0	0	0	0	1	0				
36	0	0	0	0	0	1	0				
38	0	0	0	0	0	1	0				
40	0	0	0	0	0	1	0				
42	0	0	0	0	0	1	0				
44	0	0	0	0	0	1	0				
46	0	0	0	0	0	1	0				
48	0	0	0	0	0	1	0				
50	0	0	0	0	0	1	0				
52	0	0	0	0	0	1	0				
54	0	0	0	0	0	2	0				
56	0	0	0	0	0	3	0				
58	0	0	0	0	0	6	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 93 at 150 min
Preheater Deposit Code: 1
TDR Spun Deposit Rating: 1 at 44

JET A-1 WITH TETRALIN (5%) AL-13633-T AT 246°C (475°F)—TEST 552T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	3	0				
04	0	0	0	0	0	2	0				
06	0	0	0	0	0	1	0				
08	0	0	0	0	0	1	0				
10	0	0	0	0	0	2	0				
12	0	0	0	0	0	2	0				
14	0	0	0	0	0	3	0				
16	0	0	0	0	0	1	0				
18	0	0	0	0	0	2	0				
20	0	0	0	0	0	1	0				
22	0	0	0	0	0	1	0				
24	0	0	0	0	0	1	0				
26	0	0	0	0	0	1	0				
28	0	0	0	0	0	1	0				
30	0	0	0	0	0	1	0				
32	0	0	0	0	0	1	0				
34	0	0	0	0	0	1	0				
36	0	0	0	0	0	1	0				
38	0	0	0	0	0	2	0				
40	0	0	0	0	0	2	0				
42	0	0	0	0	0	2	0				
44	0	0	0	0	0	1	0				
46	0	0	0	0	0	2	0				
48	0	0	0	0	0	2	0				
50	0	0	0	0	0	1	0				
52	0	0	0	0	0	1	0				
54	0	0	0	0	0	1	0				
56	0	0	0	0	0	2	0				
58	0	0	0	0	0	5	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 45 at 150 min
Preheater Deposit Code: 1
TDR Spun Deposit Rating: 2 at 40

JET A-1 WITH TETRALIN (5%) AL-13633-T AT 246°C (475°F)—TEST 553J*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	4	0				
04	0	0	0	0	0	3	0				
06	0	0	0	0	0	2	0				
08	0	0	0	0	0	2	0				
10	0	0	0	0	0	2	0				
12	0	0	0	0	0	2	0				
14	0	0	0	0	0	2	0				
16	0	0	0	0	0	2	0				
18	0	0	0	0	0	2	0				
20	0	0	0	0	0	2	0				
22	0	0	0	0	0	2	0				
24	0	0	0	0	0	2	0				
26	0	0	0	0	0	2	0				
28	0	0	0	0	0	3	0				
30	0	0	0	0	0	3	0				
32	0	0	0	0	0	3	0				
34	0	0	0	0	0	3	0				
36	0	0	0	0	0	3	0				
38	0	0	0	0	0	3	0				
40	0	0	0	0	0	3	0				
42	0	0	0	0	0	3	0				
44	0	0	0	0	0	3	0				
46	0	0	0	0	0	3	0				
48	0	0	0	0	0	2	0				
50	0	0	0	0	0	2	0				
52	0	0	0	0	0	2	0				
54	0	0	0	0	0	2	0				
56	0	0	0	0	0	3	0				
58	0	0	0	0	0	6	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 20 at 150 min
Preheater Deposit Code: 1
TDR Spun Deposit Rating: 3 at 40

JET A-1 WITH TETRALIN (5%) AL-13633-T AT 260°C (500°F)--TEST 540T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	3	0				
04	0	0	0	0	0	2	0				
06	0	0	0	0	0	2	0				
08	0	0	0	0	0	2	0				
10	0	0	0	0	0	2	0				
12	0	0	0	0	0	2	0				
14	0	0	0	0	0	2	0				
16	0	0	0	0	0	2	0				
18	0	0	0	0	0	2	0				
20	0	0	0	0	0	2	0				
22	0	0	0	0	0	2	0				
24	0	0	0	0	0	2	0				
26	0	0	0	0	0	2	0				
28	0	0	0	0	0	2	0				
30	0	0	0	0	0	2	0				
32	0	0	0	0	0	2	0				
34	0	0	0	0	0	3	0				
36	0	0	0	0	0	3	0				
38	0	0	0	0	0	4	0				
40	0	0	0	0	0	4	0				
42	0	0	0	0	0	4	0				
44	0	0	0	0	0	4	0				
46	0	0	0	0	0	4	0				
48	0	0	0	0	0	4	0				
50	0	0	0	0	0	4	0				
52	0	0	0	0	0	4	0				
54	0	0	0	0	0	5	0				
56	0	0	0	0	0	5	0				
58	0	0	0	0	0	11	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 138 min
Preheater Deposit Code: 2
TDR Spun Deposit Rating: 4 at 46

JET A-1 WITH TETRALIN (5%) AL-13633-T AT 260°C (500°F)--TEST 545T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	3	0				
04	0	0	0	0	0	2	0				
06	0	0	0	0	0	2	0				
08	0	0	0	0	0	2	0				
10	0	0	0	0	0	2	0				
12	0	0	0	0	0	2	0				
14	0	0	0	0	0	2	0				
16	0	0	0	0	0	2	0				
18	0	0	0	0	0	2	0				
20	0	0	0	0	0	2	0				
22	0	0	0	0	0	2	0				
24	0	0	0	0	0	2	0				
26	0	0	0	0	0	2	0				
28	0	0	0	0	0	2	0				
30	0	0	0	0	0	2	0				
32	0	0	0	0	0	4	0				
34	0	0	0	0	0	3	0				
36	0	0	0	0	0	3	0				
38	0	0	0	0	0	3	0				
40	0	0	0	0	0	4	0				
42	0	0	0	0	0	4	0				
44	0	0	0	0	0	4	0				
46	0	0	0	0	0	4	0				
48	0	0	0	0	0	4	0				
50	0	[illegible]	[illegible]	0	0	4	0				
52	[illegible]	0	0	0	0	5	0				
54	0	0	0	0	0	3	0				
56	0	0	0	0	0	5	0				
58	0	0	0	0	0	6	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 75 at 150 min
Preheater Deposit Code: >2
TDR Spun Deposit Rating: 4 at 46

JET A-1 WITH TETRALIN (5%) AL-13633-T AT 260°C (500°F)—TEST 546T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	[illegible]	0				
04	0	0	0	0	0	2	0				
06	0	0	0	0	0	1	0				
08	0	0	0	0	0	1	0				
10	0	0	0	0	0	1	0				
12	0	0	0	0	0	1	0				
14	0	0	0	0	0	1	0				
16	0	0	0	0	0	1	0				
18	0	0	0	0	0	0	0				
20	0	0	0	0	0	0	0				
22	0	0	0	0	0	0	0				
24	0	0	0	0	0	0	0				
26	0	0	0	0	0	0	0				
28	0	0	0	0	0	0	0				
30	0	0	0	0	0	0	0				
32	0	0	0	0	0	1	0				
34	0	0	0	0	0	1	0				
36	0	0	0	0	0	1	0				
38	0	0	0	0	0	1	0				
40	0	0	0	0	0	2	0				
42	0	0	0	0	0	2	0				
44	0	0	0	0	0	2	0				
46	0	0	0	0	0	2	0				
48	0	0	0	0	0	[illegible]	0				
50	0	0	0	0	0	2	0				
52	0	0	0	0	0	2	0				
54	0	0	0	0	0	3	0				
56	0	0	0	0	0	4	0				
58	0	0	0	0	0	11	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 132 min
Preheater Deposit Code: 2
TDR Spun Deposit Rating: 2 at 46

JET A-1 WITH TETRALIN (5%) AL-13633-T AT 268°C (515°F)—TEST 547J*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	4	0				
04	0	0	0	0	0	3	0				
06	0	0	0	0	0	3	0				
08	0	0	0	0	0	3	0				
10	0	0	0	0	0	3	0				
12	0	0	0	0	0	3	0				
14	0	0	0	0	0	3	0				
16	0	0	0	0	0	3	0				
18	0	0	0	0	0	3	0				
20	0	0	0	0	0	3	0				
22	0	0	0	0	0	3	0				
24	0	0	0	0	0	3	0				
26	0	0	0	0	0	3	0				
28	0	0	0	0	0	4	0				
30	0	0	0	0	0	4	0				
32	0	0	0	0	0	5	0				
34	0	0	0	0	0	6	0				
36	0	0	0	0	0	8	0				
38	0	0	0	0	0	10	0				
40	0	0	0	0	0	13	1				
42	0	0	0	0	0	13	2				
44	0	0	0	0	0	13	2				
46	0	0	0	0	0	13	2				
48	0	0	0	0	0	12	2				
50	0	0	0	0	0	10	2				
52	0	0	0	0	0	8	1				
54	0	0	0	0	0	6	0				
56	0	0	0	0	0	5	0				
58	0	0	0	0	0	5	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 142 min
Preheater Deposit Code: 3
TDR Spun Deposit Rating: 13 at 44

JET A-1 WITH TETRALIN (5%) AL-13633-T AT 268°C (515°F)--TEST 548T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	3	0				
04	0	0	0	0	0	2	0				
06	0	0	0	0	0	2	0				
08	0	0	0	0	0	2	0				
10	0	0	0	0	0	2	0				
12	0	0	0	0	0	2	0				
14	0	0	0	0	0	3	0				
16	0	0	0	0	0	3	0				
18	0	0	0	0	0	3	0				
20	0	0	0	0	0	3	0				
22	0	0	0	0	0	2	0				
24	0	0	0	0	0	2	0				
26	0	0	0	0	0	2	0				
28	0	0	0	0	0	1	0				
30	0	0	0	0	0	1	0				
32	0	0	0	0	0	1	0				
34	0	0	0	0	0	1	0				
36	0	0	0	0	0	1	0				
38	0	0	0	0	0	0	0				
40	0	0	0	0	0	0	0				
42	0	0	0	0	0	0	0				
44	0	0	0	0	0	0	0				
46	0	0	0	0	0	0	0				
48	0	0	0	0	0	0	0				
50	0	0	0	0	0	0	0				
52	0	0	0	0	0	0	0				
54	0	0	0	0	0	0	0				
56	0	0	0	0	0	1	0				
58	0	0	0	0	0	2	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
- Change in Pressure Drop, mm of Hg: 125 at 112 min
- Preheater Deposit Code: 2
- TDR Spun Deposit Rating: 3 at 18

JET A-1 WITH TETRALIN (5%) AL-13633-T AT 268°C (515°F)--TEST 551J*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	4	0				
04	0	0	0	0	0	2	0				
06	0	0	0	0	0	2	0				
08	0	0	0	0	0	2	0				
10	0	0	0	0	0	2	0				
12	0	0	0	0	0	2	0				
14	0	0	0	0	0	2	0				
16	0	0	0	0	0	2	0				
18	0	0	0	0	0	2	0				
20	0	0	0	0	0	2	0				
22	0	0	0	0	0	2	0				
24	0	0	0	0	0	2	0				
26	0	0	0	0	0	2	0				
28	0	0	0	0	0	3	0				
30	0	0	0	0	0	3	0				
32	0	0	0	0	0	4	0				
34	0	0	0	0	0	5	0				
36	0	0	0	0	0	[illegible]	0				
38	0	0	0	0	0	6	0				
40	0	0	0	0	0	7	1				
42	0	0	0	0	0	8	2				
44	0	0	0	0	0	8	2				
46	0	0	0	0	0	8	2				
48	0	0	0	0	0	7	2				
50	0	0	0	0	0	5	1				
52	0	0	0	0	0	3	1				
54	0	0	0	0	0	3	0				
56	0	0	0	0	0	3	0				
58	0	0	0	0	0	3	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
- Change in Pressure Drop, mm of Hg: 103 at 156 min
- Preheater Deposit Code: 3
- TDR Spun Deposit Rating: 8 at 44

JET A-1 WITH TETRALIN (5%) AL-13633-T AT 274°C (525°F)—TEST 539J*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	3	0				
04	0	0	0	0	0	1	0				
06	0	0	0	0	0	1	0				
08	0	0	0	0	0	1	0				
10	0	0	0	0	0	1	0				
12	0	0	0	0	0	1	0				
14	0	0	0	0	0	1	0				
16	0	0	0	0	0	1	0				
18	0	0	0	0	0	1	0				
20	0	0	0	0	0	1	0				
22	0	0	0	0	0	1	0				
24	0	0	0	0	0	1	0				
26	0	0	0	0	0	1	0				
28	0	0	0	0	0	1	0				
30	0	0	0	0	0	2	0				
32	0	0	0	0	0	2	0				
34	0	0	0	0	0	3	0				
36	0	0	0	0	0	4	0				
38	0	0	0	0	0	7	2				
40	0	0	0	0	0	9	3				
42	0	0	0	0	0	10	4				
44	0	0	0	0	0	10	4				
46	0	0	0	0	0	9	3				
48	0	0	0	0	0	7	2				
50	0	0	0	0	0	3	2				
52	0	0	0	0	0	3	0				
54	0	0	0	0	0	2	0				
56	0	0	0	0	0	2	0				
58	0	0	0	0	0	2	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 131 min
Preheater Deposit Code: 3
TDR Spun Deposit Rating: 10 at 44

JET A-1 WITH TETRALIN (5%) AL-13633-T AT 274°C (525°F)—TEST 541J*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	6	0				
04	0	0	0	0	0	4	0				
06	0	0	0	0	0	3	0				
08	0	0	0	0	0	3	0				
10	0	0	0	0	0	2	0				
12	0	0	0	0	0	2	0				
14	0	0	0	0	0	1	0				
16	0	0	0	0	0	2	0				
18	0	0	0	0	0	2	0				
20	0	0	0	0	0	1	0				
22	0	0	0	0	0	1	0				
24	0	0	0	0	0	2	0				
26	0	0	0	0	0	2	0				
28	0	0	0	0	0	2	0				
30	0	0	0	0	0	1	0				
32	0	0	0	0	0	3	1				
34	0	0	0	0	0	5	2				
36	0	0	0	0	0	9	4				
38	0	0	0	0	0	10	4				
40	0	0	0	0	0	10	4				
42	0	0	0	0	0	9	4				
44	0	0	0	0	0	9	<4 (P)				
46	0	0	0	0	0	9	<4 (P)				
48	0	0	0	0	0	10	<4 (P)				
50	0	0	0	0	0	9	<4 (P)				
52	0	0	0	0	0	7	2				
54	0	0	0	0	0	5	2				
56	0	0	0	0	0	5	2				
58	0	0	0	0	0	9	1				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 114 at 150 min
Preheater Deposit Code: >3
TDR Spun Deposit Rating: 10 at 40

JET A-1 WITH TETRALIN (5%) AL-13633-T AT 274°C (525°F)—TEST 542T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	4	0				
04	0	0	0	0	0	3	0				
06	0	0	0	0	0	3	0				
08	0	0	0	0	0	3	0				
10	0	0	0	0	0	3	0				
12	0	0	0	0	0	3	0				
14	0	0	0	0	0	3	0				
16	0	0	0	0	0	3	0				
18	0	0	0	0	0	3	0				
20	0	0	0	0	0	3	0				
22	0	0	0	0	0	3	0				
24	0	0	0	0	0	3	0				
26	0	0	0	0	0	3	0				
28	0	0	0	0	0	3	0				
30	0	0	0	0	0	4	0				
32	0	0	0	0	0	4	0				
34	0	0	0	0	0	5	1				
36	0	0	0	0	0	7	2				
38	0	0	0	0	0	11	3				
40	0	0	0	0	0	13	4				
42	0	0	0	0	0	13	4				
44	0	0	0	0	0	13	4				
46	0	0	0	0	0	13	4				
48	0	0	0	0	0	12	4				
50	0	0	0	0	0	10	3				
52	0	0	0	0	0	7	2				
54	0	0	0	0	0	5	0				
56	0	0	0	0	0	5	0				
58	0	0	0	0	0	7	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 106 min
Preheater Deposit Code: 4
TDR Spun Deposit Rating: 13 at 44

JET A-1 WITH TETRALIN (5%) AL-13633-T AT 288°C (550°F)—TEST 543J*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	4	0				
04	0	0	0	0	0	1	0				
06	0	0	0	0	0	2	0				
08	0	0	0	0	0	2	0				
10	0	0	0	0	0	2	0				
12	0	0	0	0	0	2	0				
14	0	0	0	0	0	2	0				
16	0	0	0	0	0	2	0				
18	0	0	0	0	0	2	0				
20	0	0	0	0	0	2	0				
22	0	0	0	0	0	3	0				
24	0	0	0	0	0	3	0				
26	0	0	0	0	0	3	0				
28	0	0	0	0	0	4	0				
30	0	0	0	0	0	4	2				
32	0	0	0	0	0	7	3				
34	0	0	0	0	0	12	4				
36	0	0	0	0	0	8	4				
38	0	22.2	71.7	44.2	34.3	18	4				
40	43.4	52.2	10.8	76.6	46.3	25	4				
42	96.7	103.7	95.7	78.0	92.3	31	4				
44	96.0	92.3	29.5	46.9	83.7	33	4				
46	52.1	56.3	96.0	53.5	63.9	31	4				
48	39.4	17.2	6.6	39.4	25.7	28	3				
50	29.9	22.8	20.9	33.6	27.3	23	2				
52	15.9	5.6	2.0	11.5	8.8	19	2				
54	0	3.0	0	0	0.8	14	2				
56	0	0	0	0	0	10	2				
58	0	0	0	0	0	10	0				
TOTAL	373.4	375.3	376.2	403.9	383.3						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 107 min
Preheater Deposit Code: >4
TDR Spun Deposit Rating: 33 at 44

JET A-1 WITH TETRALIN (5%) AL-13633-T AT 288°C (550°F)—TEST 544T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	3	0				
04	0	0	0	0	0	3	0				
06	0	0	0	0	0	3	0				
08	0	0	0	0	0	3	0				
10	0	0	0	0	0	3	0				
12	0	0	0	0	0	2	0				
14	0	0	0	0	0	2	0				
16	0	0	0	0	0	2	0				
18	0	0	0	0	0	2	0				
20	0	0	0	0	0	3	0				
22	0	0	0	0	0	3	0				
24	0	0	0	0	0	3	0				
26	0	0	0	0	0	3	0				
28	0	0	0	0	0	4	0				
30	0	0	0	0	0	6	2				
32	0	0	0	0	0	12	3 (P)				
34	0	9.0	0	1.0	2.5	7	4 (P)				
36	28.4	12.1	65.3	15.0	25.2	11	>4 (P)				
38	14.9	22.5	53.0	37.8	32.1	17	>4 (P)				
40	61.0	23.1	48.8	50.3	[illegible]	24	3				
42	102.2	7.6	100.1	91.8	75.4	28	3				
44	84.5	45.6	79.8	59.9	67.5	28	3				
46	63.4	27.0	20.6	62.3	43.3	25	3				
48	42.3	28.0	45.4	48.3	41.0	21	2				
50	50.9	0	19.8	60.7	32.9	17	2				
52	0	27.0	5.7	15.0	11.9	14	2				
54	0	0	0	0	0	5	2				
56	0	0	0	0	0	6	2				
58	0	0	0	0	0	6	0				
TOTAL	447.6	201.9	418.3	442.1	377.6						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 91 min
Preheater Deposit Code: >4
TDR Spun Deposit Rating: 28 at 44

JET A-1 WITH TETRALIN (5%) AL-13633-T AT 288°C (550°F)—TEST 550T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	2	0				
04	0	0	0	0	0	1	0				
06	0	0	0	0	0	0	0				
08	0	0	0	0	0	[illegible]	0				
10	0	0	0	0	0	0	0				
12	0	0	0	0	0	0	0				
14	0	0	0	0	0	0	0				
16	0	0	0	0	0	0	0				
18	0	0	0	0	0	0	0				
20	0	0	0	0	0	0	0				
22	0	0	0	0	0	1	0				
24	0	0	0	0	0	1	0				
26	0	0	0	0	0	2	0				
28	0	0	0	0	0	[illegible]	0				
30	0	0	0	0	0	3	0				
32	0	0	0	0	0	3	0				
34	2.0	2.0	2.0	0	1.5	11	2				
36	22.6	28.8	3.0	0	13.6	8	4				
38	42.4	20.9	5.0	10.0	17.1	11	4				
40	34.6	56.5	65.7	50.3	51.7	18	3	<0.2 μm		<0.2 μm	
42	100.3	86.6	151.9	66.3	101.3	22	3	0.2-0.3 μm			
44	58.1	93.6	5.0	89.4	68.5	23	3		0.2-0.3 μm		
46	57.9	53.8	50.7	180.2	[illegible]	21	3				
48	27.9	24.8	26.2	58.8	34.4	16	3				
50	44.0	70.0	33.4	46.2	48.4	13	[illegible]				
52	3.0	0	8.0	19.0	7.5	10	2				
54	0	0	0	0	0	6	2				
56	0	0	0	0	0	4	2				
58	0	0	0	0	0	4	1				
TOTAL	422.6	426.8	338.9	520.2	427.2						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 91 min
Preheater Deposit Code: >4
TDR Spun Deposit Rating: 23 at 44

JET A-1 WITH THIOPHENE AND TETRALIN AL-13636-T AT 302°C (500°F)—TEST 564J*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	7	0				
04	0	0	0	0	0	4	0				
06	0	0	0	0	0	5	0				
08	0	0	0	0	0	3	0				
10	0	0	0	0	0	3	0				
12	2.6	0	0	0	0.7	3	0				
14	0	0	0	0	0	3	0				
16	0	0	0	0	0	3	0				
18	0	0	0	0	0	3	0				
20	0	0	0	0	0	3	0				
22	0	0	0	0	0	3	0				
24	0	0	0	0	0	3	0				
26	0	0	0	0	0	3	0				
28	0	0	0	0	0	3	0				
30	0	0	0	0	0	4	0				
32	0	0	0	0	0	5	0				
34	0	0	0	2.2	0.6	4	0				
36	0	0	0	2.5	0.6	5	1				
38	0	0	0	1.8	0.5	6	2				
40	0	0	2.6	1.5	1.0	7	2				
42	0	0	0	1.5	0.4	7	2				
44	0	0	4.7	1.6	1.6	8	2				
46	0	0	4.0	0	1.0	8	2				
48	0	0	4.9	0	1.2	7	2				
50	0	0	3.0	0	0.8	6	1				
52	0	0	0	0	0	6	0				
54	0	0	0	0	0	5	0				
56	0	0	0	0	0	5	0				
58	0	0	0	0	0	10	0				
TOTAL	2.6	0	19.2	11.1	8.4						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 110 at 150 min
Preheater Deposit Code: 1
TDR Spun Deposit Rating: 8 at 44

JET A-1 WITH THIOPHENE AND TETRALIN AL-13636-T AT 260°C (500°F)—TEST 571T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	3	0				
04	0	0	0	0	0	3	0				
06	0	0	0	0	0	3	0				
08	0	0	0	0	0	3	0				
10	0	0	0	0	0	2	0				
12	0	0	0	0	0	2	0				
14	0	0	0	0	0	2	0				
16	0	0	0	0	0	3	0				
18	0	0	0	0	0	2	0				
20	0	0	0	0	0	2	0				
22	0	0	0	0	0	2	0				
24	0	0	0	0	0	2	0				
26	0	0	0	0	0	2	0				
28	0	0	0	0	0	2	0				
30	0	0	0	0	0	3	0				
32	0	0	0	0	0	3	0				
34	0	0	0	0	0	5	0				
36	0	0	0	0	0	5	0				
38	0	0	0	0	0	4	0				
40	0	0	0	0	0	4	0				
42	0	0	0	0	0	4	0				
44	0	0	0	0	0	4	0				
46	0	0	0	0	0	4	0				
48	0	0	0	0	0	5	0				
50	0	0	0	0	0	3	0				
52	0	0	0	0	0	4	0				
54	0	0	0	0	0	3	0				
56	0	0	0	0	0	4	0				
58	0	0	0	0	0	7	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 146 min
Preheater Deposit Code: 1
TDR Spun Deposit Rating: 4 at 44

JET A-1 WITH THIOPHENE AND TETRALIN AL-13636-T AT 260°C (500°F)—TEST 573T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	6	0				
04	0	0	0	0	0	4	0				
06	0	0	0	0	0	3	0				
08	0	0	0	0	0	2	0				
10	0	0	0	0	0	2	0				
12	0	0	0	0	0	2	0				
14	0	0	0	0	0	2	0				
16	0	0	0	0	0	2	0				
18	0	0	0	0	0	2	0				
20	0	0	0	0	0	2	0				
22	0	0	0	0	0	2	0				
24	0	0	0	0	0	2	0				
26	0	0	0	0	0	2	0				
28	0	0	0	0	0	3	0				
30	0	0	0	0	0	3	0				
32	0	0	0	0	0	3	0				
34	0	0	0	0	0	3	0				
36	0	0	0	0	0	4	0				
38	0	0	0	0	0	5	0				
40	0	0	0	0	0	6	0				
42	0	0	0	0	0	6	0				
44	0	0	0	0	0	6	0				
46	0	0	0	0	0	6	0				
48	0	0	0	0	0	7	0				
50	0	0	0	0	0	6	0				
52	0	0	0	0	0	6	0				
54	0	0	0	0	0	7	0				
56	0	0	0	0	0	8	0				
58	0	0	0	0	0	13	0				
TOTAL	0	0	0	0	0						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 97 at 150 min
Preheater Deposit Code: 1
TDR Spun Deposit Rating: 7 at 48

JET A-1 WITH THIOPHENE AND TETRALIN AL-13636-T AT 274°C (525°F)—TEST 565J*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	3	0				
04	0	0	0	0	0	2	0				
06	0	0	0	0	0	2	0				
08	0	0	0	0	0	2	0				
10	0	0	0	0	0	3	0				
12	0	0	0	0	0	3	0				
14	0	0	0	0	0	3	0				
16	0	0	0	0	0	3	0				
18	0	0	0	0	0	3	0				
20	0	0	0	0	0	3	0				
22	0	0	0	0	0	3	0				
24	0	0	0	0	0	3	0				
26	0	0	0	0	0	3	0				
28	0	0	0	0	0	4	0				
30	0	0	0	0	0	5	2				
32	0	0	0	1.0	0.3	6	3				
34	0	0	0	2.0	0.5	8	4				
36	0	3.8	3.0	5.9	3.2	12	4				
38	19.4	3.6	3.3	4.3	7.6	12	4				
40	39.1	11.6	24.7	0	18.7	12	4				
42	3.3	0	6.0	1.6	3.3	11	4				
44	41.6	0	0	29.8	17.8	11	4				
46	2.0	0	3.0	62.0	16.8	12	4				
48	0	0	76.0	3.8	20.0	12	4				
50	0	2.6	11.7	56.8	17.7	10	4				
52	0	1.0	4.1	24.0	7.3	7	2				
54	0	18.0	0	0	4.5	5	1				
56	0	0	0	0	0	4	1				
58	0	0	0	0	0	4	0				
TOTAL	105.4	40.0	129.3	195.6	117.9						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 135 min
Preheater Deposit Code: >2
TDR Spun Deposit Rating: 12 at 38

JET A-1 WITH THIOPHENE AND TETRALIN AL-13636-T AT 274°C (525°F)—TEST 574J*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	5	0				
04	0	0	0	0	0	4	0				
06	0	0	0	0	0	3	0				
08	0	0	0	0	0	3	0				
10	0	0	0	0	0	3	0				
12	0	0	0	0	0	3	0				
14	0	0	0	0	0	3	0				
16	0	0	0	0	0	3	0				
18	0	0	0	0	0	3	0				
20	0	0	0	0	0	3	0				
22	0	0	0	0	0	3	0				
24	0	0	0	0	0	4	0				
26	0	0	0	0	0	4	0				
28	0	0	0	0	0	5	0				
30	0	0	0	0	0	6	1				
32	1.0	0	0	0	0.3	8	2				
34	0	1.0	0	0	0.3	11	3				
36	0	2.0	0	3.8	1.5	13	3				
38	0	0	5.9	3.7	2.4	13	4				
40	1.4	9.2	0	0	2.7	11	4				
42	14.5	1.0	3.1	4.3	5.7	11	2				
44	0	0	16.7	15.8	8.1	11	2				
46	0	6.0	0	0	1.5	12	2				
48	0	5.0	0	31.2	9.1	12	2				
50	0	0	0	29.8	7.5	13	2				
52	6.1	0	0	16.4	5.6	11	2				
54	0	0	0	3.0	0.8	8	1				
56	0	0	0	0	0	6	1				
58	0	0	0	0	0	7	0				
TOTAL	23.0	24.2	25.7	109.0	45.5						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 107 at 150 min
Preheater Deposit Code: >2P
TDR Spun Deposit Rating: 13 at 38

JET A-1 WITH THIOPHENE AND TETRALIN AL-13636-T AT 281°C (538°F)—TEST 566J*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	5	0				
04	0	0	0	0	0	5	0				
06	0	0	0	0	0	5	0				
08	0	0	0	0	0	4	0				
10	0	0	0	0	0	5	0				
12	0	0	0	0	0	4	0				
14	0	0	0	0	0	5	0				
16	0	0	0	0	0	5	0				
18	0	0	0	0	0	4	0				
20	0	0	0	0	0	5	0				
22	0	0	0	0	0	5	0				
24	0	0	0	0	0	5	0				
26	0	0	0	0	0	5	0				
28	0	0	0	0	0	6	0				
30	0	0	0	0	0	7	2				
32	0	0	0	0	0	10	1				
34	0	0	3.9	0	1.0	13	4				
36	15.8	0	5.6	4.2	5.8	12	4				
38	28.4	0	5.3	15.2	12.2	10	4				
40	62.7	46.7	32.9	7.6	37.5	12	3				
42	55.1	72.0	20.1	37.2	46.1	14	3				
44	32.3	18.4	40.9	44.1	33.9	13	3				
46	43.6	0	32.6	21.8	24.5	16	3				
48	60.8	12.2	23.7	22.2	29.7	16	2				
50	2.0	37.1	28.7	12.6	20.1	16	2				
52	1.0	5.0	14.4	12.6	7.8	15	2				
54	2.0	0	0	0	0.5	12	2				
56	0	0	0	0	0	8	2				
58	0	0	0	0	0	7	0				
TOTAL	318.5	229.6	205.5	197.5	238.1						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 111 min
Preheater Deposit Code: 3P
TDR Spun Deposit Rating: 16 at 48

JET A-1 WITH THIOPHENE AND TETRALIN AL-13636-T AT 281°C (538°F)—TEST 567T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	6	0				
04	0	0	0	0	0	4	0				
06	0	0	0	0	0	3	0				
08	0	0	0	0	0	3	0				
10	0	0	0	0	0	3	0				
12	0	0	0	0	0	2	0				
14	0	0	0	0	0	2	0				
16	0	0	0	0	0	2	0				
18	0	0	0	0	0	2	0				
20	0	0	0	0	0	2	0				
22	0	0	0	0	0	2	0				
24	0	0	0	0	0	3	0				
26	0	0	0	0	0	3	0				
28	0	0	0	0	0	4	2				
30	0	0	5.2	0	1.3	5	3				
32	0	0	2.8	2.1	1.2	8	4				
34	3.4	0	6.7	3.3	3.4	12	4				
36	14.0	4.9	0	3.0	5.5	10	4				
38	8.2	4.9	0	5.5	4.7	8	4				
40	54.0	4.3	0	6.4	16.2	11	3				
42	44.3	45.0	40.3	4.2	33.5	13	4				
44	41.4	77.1	55.0	100.4	68.5	14	4				
46	77.1	57.4	51.5	77.7	65.9	14	4				
48	20.3	6.3	5.8	93.1	31.4	12	4				
50	29.3	32.3	3.8	189.7	63.8	11	3				
52	7.2	19.3	144.8	47.8	54.8	11	4				
54	3.8	0	24.3	7.6	8.9	9	4				
56	5.0	0	0	0	1.3	6	4				
58	0	0	0	0	0	6	0				
TOTAL	308.2	251.5	340.2	540.8	360.4						

*JFTOT, D 3241
- Change in Pressure Drop, mm of Hg: 125 at 60 min
- Preheater Deposit Code: 3P
- TDR Spun Deposit Rating: 14 at 44

JET A-1 WITH THIOPHENE AND TETRALIN AL-13636-T AT 281°C (538°F)—TEST 578T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	4	0				
04	0	0	0	0	0	3	0				
06	0	0	0	0	0	3	0				
08	0	0	0	0	0	3	0				
10	0	0	0	0	0	3	0				
12	0	0	0	0	0	3	0				
14	0	0	0	0	0	4	0				
16	0	0	0	0	0	4	0				
18	0	0	0	0	0	3	0				
20	0	0	0	0	0	4	0				
22	0	0	0	0	0	4	0				
24	0	0	0	0	0	4	0				
26	0	0	0	0	0	4	0				
28	0	0	0	0	0	3	0				
30	0	0	0	0	0	4	0				
32	0	4.0	[illegible]	0	1.8	8	0				
34	0	7.3	5.6	4.7	3.8	11	2				
36	2.2	3.9	0	12.6	4.7	13	3				
38	3.0	5.1	2.7	16.9	5.9	12	4				
40	8.2	13.5	6.6	55.8	18.8	12	5				
42	3.6	49.5	31.6	6.1	23.2	13	4				
44	25.5	49.7	32.8	29.6	31.9	14	4(P)				
46	22.0	5.5	60.9	8.9	19.3	14	3				
48	18.6	0	0	6.9	[illegible]	14	3				
50	0	26.9	0	54.3	20.6	13	2				
52	0	0	0	0	0	10	2				
54	0	0	0	0	0	6	2				
56	0	0	0	0	0	4	1				
58	0	0	0	0	0	3	0				
TOTAL	83.9	155.1	138.2	182.8	136.1						

*JFTOT, D 3241
- Change in Pressure Drop, mm of Hg: 125 at 124 min
- Preheater Deposit Code: 3P
- TDR Spun Deposit Rating: 14 at 46

JET A-1 WITH THIOPHENE AND TETRALIN AL-13636-T AT 288°C (550°F)—TEST 575T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	7	0				
04	0	0	0	0	0	6	0				
06	0	0	0	0	0	5	0				
08	0	0	0	0	0	5	0				
10	0	0	0	0	0	5	0				
12	0	0	0	0	0	5	0				
14	0	0	0	0	0	4	0				
16	0	0	0	0	0	5	0				
18	0	0	0	0	0	5	0				
20	0	0	0	0	0	4	0				
22	0	0	0	0	0	5	0				
24	0	0	0	0	0	5	0				
26	0	0	0	0	0	5	0				
28	0	0	0	0	0	7	0				
30	3.1	0	0	0	0.8	11	2				
32	51.5	3.3	0	0	13.7	14	3				
34	4.9	0	8.8	14.8	7.1	9	4				
36	72.2	0	38.0	11.3	30.4	17	>4 (P)				
38	79.0	42.1	111.2	99.4	82.9	26	>4 (P)				
40	110.4	99.7	104.0	75.2	97.3	35	3				
42	148.0	119.9	148.0	134.6	137.6	38	3				
44	11.0	154.6	106.5	54.0	81.5	38	2				
46	0	46.2	7.7	81.7	33.[illegible]	37	2				
48	41.1	54.5	12.6	67.2	48.9	33	2				
50	0	46.5	22.9	40.0	27.4	26	2				
52	29.6	3.8	10.4	7.2	12.8	19	2				
54	6.9	19.8	3.6	0	7.5	16	2				
56	0	4.2	5.3	0	2.4	13	2				
58	2	3.9	2.2	0	2.0	14	1				
TOTAL	559.7	597.5	601.0	585.4	586.2						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 96 min
Preheater Deposit Code: >3
TDR Spun Deposit Rating: 38 at 44

JET A-1 WITH THIOPHENE AND TETRALIN AL-13636-T AT 288°C (550°F)—TEST 576T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	2	0				
04	0	0	0	0	0	1	0				
06	0	0	0	0	0	[illegible]	0				
08	0	0	0	[illegible]	[illegible]	[illegible]	0				
10	0	[illegible]	0	0	0	2	0				
12	0	[illegible]	0	0	[illegible]	1	[illegible]				
14	[illegible]	0	0	0	0	1	0				
16	0	0	0	0	0	2	0				
18	0	0	0	0	0	[illegible]	[illegible]				
20	0	0	0	0	0	2	0				
22	0	0	0	0	0	2	0				
24	0	0	0	0	0	2	0				
26	0	0	0	0	0	3	0				
28	[illegible]	[illegible]	0	0	0	4	2				
30	[illegible]	[illegible]	[illegible]	0	0	5	4				
32	3.0	1.4	[illegible]	0	2.3	4	4 (P)				
34	6.9	2.[illegible]	0	0	2.4	10	>4 (P)				
36	50.2	16.5	4.5	0	17.8	9	4				
38	31.4	46.6	49.[illegible]	0	45.4	13	4				
40	92.2	[illegible]	[illegible]	91.7	[illegible]	21	4				
42	4.4	47.5	40.1	107.3	[illegible]	16	4				
44	100.5	52.4	88.2	162.2	100.8	27	4				
46	95.4	50.8	96.0	44.0	71.6	24	4				
48	39.1	45.5	87.2	79.1	62.7	19	3				
50	41.9	55.8	56.6	1.0	[illegible]	15	3				
52	[illegible]	0	1.4	17.4	7.6	11	2				
54	5.5	6.8	4.0	0	4.6	7	2				
56	17.3	0	0	0	5.3	4	1				
58	5.3	[illegible]	[illegible]	0	[illegible]	4	1				
TOTAL	579.5	[illegible]	426.8	563.2	[illegible]						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 92 min
Preheater Deposit Code: 3
TDR Spun Deposit Rating: 27 at 44

JET A-1 WITH THIOPHENE AND TETRALIN AL-13636-T AT 288°C (550°F)—TEST 377J*

Tube Station	Dielectric Strength, Volts					MARK 9 TDR	Visual Rating	Thickness Measurements			
	0°	90°	180°	270°	Dielectric Average			0°	90°	180°	270°
02	0	0	0	0	0	2	0				
04	0	0	0	0	0	2	0				
06	0	0	0	0	0	2	0				
08	0	0	0	0	0	1	0				
10	0	0	0	0	0	2	0				
12	0	0	0	0	0	2	0				
14	0	0	0	0	0	2	0				
16	0	0	0	0	0	2	0				
18	0	0	0	0	0	2	0				
20	0	0	0	0	0	3	0				
22	0	0	0	0	0	3	0				
24	0	0	0	0	0	4	0				
26	0	0	0	0	0	6	0				
28	0	0	0	0	0	9	0				
30	0	2.6	0	3.6	1.6	12	3				
32	3.7	89.7	3.9	1.4	24.7	10	4				
34	3.2	100.5	1.9	44.8	37.6	11	>4 (P)				
36	69.0	70.7	14.5	11.2	41.4	18	4				
38	97.2	104.3	123.3	109.3	108.7	26	4				
40	22.7	16.0	80.0	127.7	61.6	29	4				
42	39.7	1.5	107.3	48.4	49.2	28	4				
44	53.7	60.2	89.2	38.4	60.4	25	4				
46	53.3	12.8	13.1	59.3	34.6	22	4				
48	3.8	62.3	5.4	18.8	22.6	17	3				
50	29.7	5.3	38.3	4.4	19.4	14	3				
52	17.3	6.5	69.3	0	22.8	10	3				
54	3.0	32.6	7.7	0	10.8	6	2				
56	0	0	27.1	0	6.8	4	0				
58	0	0	0	0	0	4	0				
TOTAL	396.9	563.2	381.0	447.3	502.7						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 123 min
Preheater Deposit Code: >3
TDR Spun Deposit Rating: 29 at 40

JET A-1 WITH THIOPHENE AND TETRALIN AL-13636-T AT 302°C (575°F)—TEST 568T*

Tube Station	Dielectric Strength, Volts					MARK 9 TDR	Visual Rating	Thickness Measurements			
	0°	90°	180°	270°	Dielectric Average			0°	90°	180°	270°
02	0	0	0	0	0	3	0				
04	0	0	0	0	0	2	0				
06	0	0	0	0	0	2	0				
08	0	0	0	0	0	2	0				
10	0	0	0	0	0	2	0				
12	0	0	0	0	0	2	0				
14	0	0	0	0	0	2	0				
16	0	0	0	0	0	2	0				
18	0	0	0	0	0	2	0				
20	0	0	0	0	0	2	0				
22	0	0	0	0	0	3	0				
24	0	0	0	0	0	4	0				
26	0	0	0	0	0	6	2				
28	0	0	3.8	0	1.5	10	4				
30	0	2.5	41.3	34.1	19.5	10	4				
32	3.3	5.1	9.0	10.1	6.9	16	>4 (P)				
34	131.6	127.6	46.3	102.1	101.9	29	4				
36	230.0	197.3	222.8	154.0	201.0	40	4				
38	213.8	235.9	155.9	232.1	208.9	44	4				
40	187.4	106.4	221.6	182.0	174.4	44	4				
42	192.0	155.4	285.1	212.5	211.3	43	4		0.5 μm	0.7 μm	
44	154.5	86.2	170.1	142.3	163.3	41	4				0.6 μm
46	137.2	138.8	159.0	110.5	133.4	37	4			0.6 μm	
48	90.2	48.4	23.3	20.0	47.5	32	4				
50	22.7	5.8	12.6	26.1	16.5	36	3				
52	28.5	22.2	16.2	0	16.7	19	4				
54	[illegible]	2.8	4.7	0	5.2	13	4				
56	0	7.6	0	0	1.9	7	3				
58	0	0	0	0	0	7	2				
TOTAL	1604.1	1138.0	1369.3	1295.8	1289.7						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 59 min
Preheater Deposit Code: 4
TDR Spun Deposit Rating: 44 at 38

JET A-1 WITH THIOPHENE AND TETRALIN AL-13636-T AT 302°C (575°F)—TEST 5693*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	4	0				
04	0	0	0	0	0	2	0				
06	0	0	0	0	0	2	0				
08	0	0	0	0	0	2	0				
10	0	0	0	0	0	2	0				
12	0	0	0	0	0	2	0				
14	0	0	0	0	0	2	0				
16	0	0	0	0	0	2	0				
18	0	0	0	0	0	2	0				
20	0	0	0	0	0	3	0				
22	3.0	0	0	0	0.8	3	0				
24	0	0	0	0	0	5	4				
26	42.9	20.0	17.7	4.2	21.2	8	4				
28	2.9	0	7.7	40.2	12.7	10	4				
30	6.0	53.5	10.2	126.2	49.0	13	>4 (P)				
32	94.4	74.8	112.3	119.5	100.2	25	4				
34	236.0	130.7	127.1	135.8	157.4	40	4				
36	405.0	252.2	200.5	157.7	253.9	42	4				
38	304.8	200.5	235.8	149.6	222.7	42	4				
40	182.2	170.6	223.5	135.1	177.9	42	4				
42	278.3	347.0	166.8	156.3	237.1	41	4				
44	100.1	14.9	39.6	80.0	58.7	38	4				
46	164.7	218.1	131.4	72.9	131.8	35	4				
48	213.0	96.7	101.4	54.6	116.4	29	3				
50	56.1	163.2	18.0	5.4	60.7	24	2				
52	61.8	5.1	20.0	0	21.7	18	2				
54	0	0	0	6.3	1.6	12	2				
56	0	0	0	0	0	8	2				
58	0	0	0	0	0	9	2				
TOTAL	2151.2	1747.3	1431.7	1263.8	1643.8						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 80 min
Preheater Deposit Code: 4
TDR Spun Deposit Rating: 42 at 38

JET A-1 WITH THIOPHENE AND TETRALIN AL-13636-T AT 302°C (575°F)—TEST 5703*

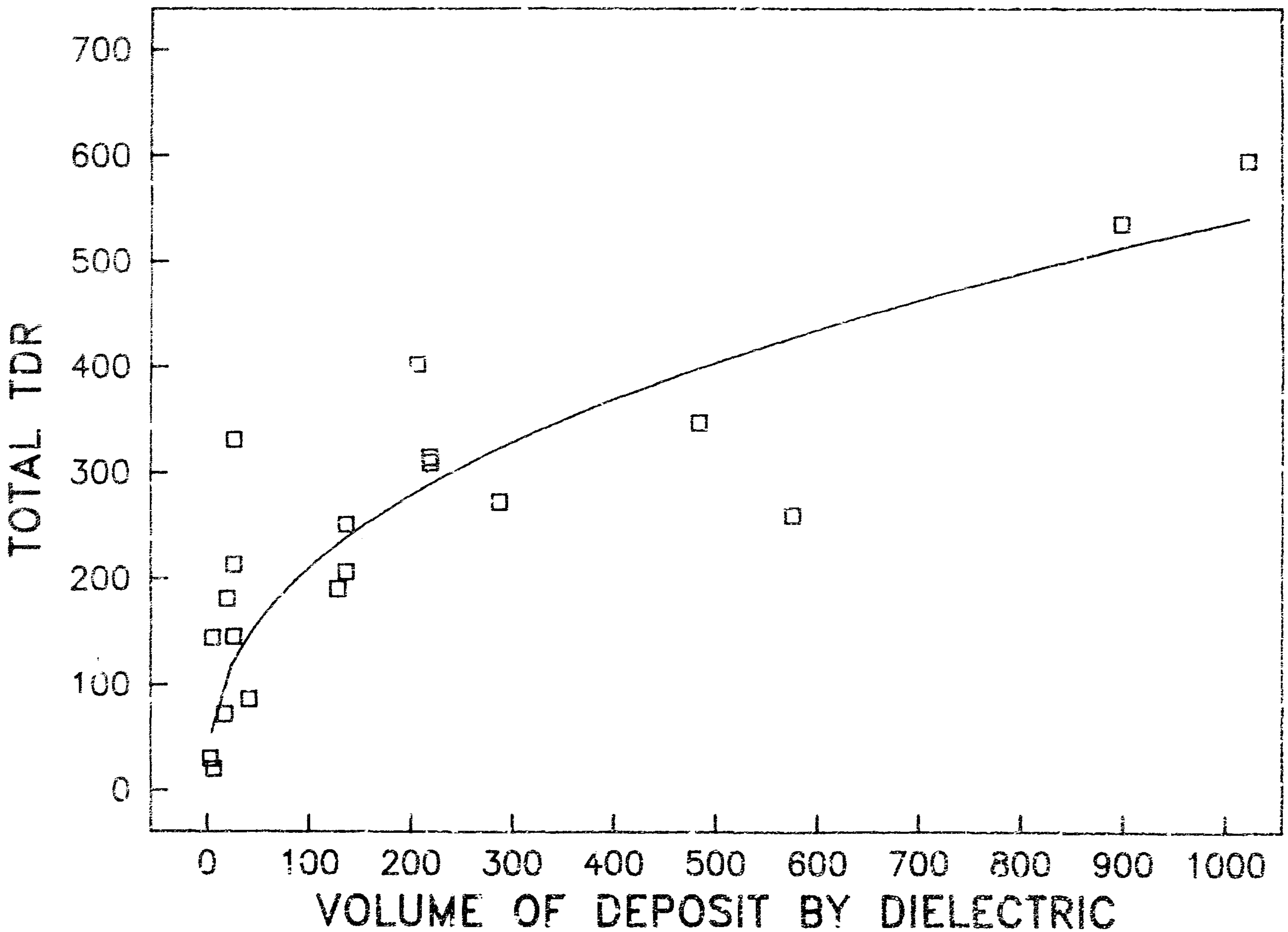
Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	MARK 9 TDR	Visual Rating	Thickness Measurement 0°	90°	180°	270°
02	0	0	0	0	0	6	0				
04	0	0	0	0	0	3	0				
06	0	0	0	0	0	2	0				
08	0	0	0	0	0	2	0				
10	0	0	0	0	0	3	0				
12	0	0	0	0	0	2	0				
14	0	0	0	0	0	2	0				
16	0	0	0	0	0	3	0				
18	0	0	0	0	0	3	0				
20	0	0	0	0	0	4	0				
22	0	0	0	0	0	7	2				
24	31.9	0	0	0	8.0	13	3				
26	28.4	12.0	7.6	5.3	13.3	8	4				
28	56.4	65.8	37.2	0	39.9	18	4				
30	0	152.2	89.3	85.2	81.7	31	4				
32	231.7	250.5	203.3	151.4	209.2	39	4				
34	180.3	132.2	203.7	128.9	161.3	42	4				
36	178.0	344.0	120.2	196.7	209.7	43	4				
38	150.9	311.8	142.9	190.1	199.0	42	4				
40	100.5	191.9	155.5	193.1	160.8	47	4				
42	50.3	188.7	133.6	110.1	120.7	39	4				
44	52.9	177.8	42.6	100.3	107.6	37	4				
46	38.8	16.9	59.4	139.2	57.8	33	4				
48	77.4	0	50.1	177.1	76.2	29	3				
50	241.4	66.2	0	79.0	96.7	26	2				
52	0	0	46.2	0	11.6	21	2				
54	31.0	0	0	0	7.8	14	1				
56	3.9	0	0	0	1.0	10	1				
58	0	0	0	0	0	11	1				
TOTAL	1488.0	1910.1	1331.6	1529.4	1567.3						

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 81 min
Preheater Deposit Code: 4
TDR Spun Deposit Rating: 43 at 36

CALCULATED DEPOSIT VOLUME COMPARED TO TDR SPUN RATINGS AT 2-mm STATIONS SUMMED OVER THE LENGTH OF TEST TUBE

Fuel (Code)	Test No.	Temp, °C (°F)	Volume of Deposit*, $cm^3 \times 10^{-7}$	Sum of TDR Spun Ratings
1% S (AL-13619-F)	521J	177 (350)	19	181
	503J	204 (400)	136	206
	524T	218 (425)	483	347
	520T	232 (450)	1022	595
	518J	260 (500)	3268	926
Cat 1-H (AL-13618-F)	508J	204 (400)	6	20
	506T	218 (425)	26	145
	498T	232 (450)	41	86
	510T	260 (500)	128	190
	497J	274 (525)	218	314
Diesel Control (AL-13630-F)	2	274 (525)	26	331
	1	288 (550)	206	402
Jet A-1 (AL-13623-T)	532T	281 (538)	3	30
	538J	288 (550)	17	72
	536J	302 (575)	575	260
Jet A-1 + Tetralin (AL-13633-T)	543J	288 (550)	219	309
Jet A-1 +Tetralin +Thiophene (AL-13636-T)	564J	260 (500)	5	144
	574J	274 (525)	26	213
	566J	281 (538)	136	251
	577J	288 (550)	287	272
	570J	302 (575)	898	535

VOLUME OF DEPOSIT COMPARED TO TOTAL TDR



APPENDIX D

TUBE MEASUREMENT PLOTS AND VOLUME OF DEPOSIT CALCULATIONS

Tube Measurement Plots and Volume of Deposit Calculations

1. Three-Dimensional Plots - Twenty-one out of the 30 selected tube tests were plotted as dielectric strength (volts) by tube angle (degrees) by tube length (mm). The nine tests that were not plotted produced only 0 dielectric strength readings. Each of these plots was rotated to a 20° angle.

2. Area Plots - The dielectric average of the four tube angles was calculated at each distinct tube length measurement. This average in volts was converted to millimeters and plotted against the tube length. All tests with the same fuel were plotted at a fixed scale. The area under each plot was shaded to represent the average area at a given plane parallel to the tube length.

3. Volume of Deposit - A first approximation estimate of the volume of the deposit on each tube was calculated as follows:

   a. The area was calculated under each quadrilateral shown on the area plots and summed over the entire length of the tube (2-58 mm). For example, the average deposit at 2 mm is 5 mm and the average deposit at 4 mm is 7 mm. To calculate the area between 2 and 4 mm, we would compute

$$\text{Area} = (4-2) * ((5 + 7)/2) = 12 \text{ mm}^2.$$

   b. The deposit area was evenly distributed over the entire length of the tube (2-58 mm) and a radius of the tube plus the deposit was calculated.

   c. The volume of the tube was computed using the formula

$$V_{TUBE} = r_T^2 h$$

where r_T is the radius (mm) and h is the tube length (56 mm).

d. The volume of the tube plus the deposit was computed

$$V_{T+D} = \pi r_{T+D}^2 h$$

where r_{T+D} is the radius (mm) of the tube plus the deposit.

e. The volume of the deposit was computed by subtraction:

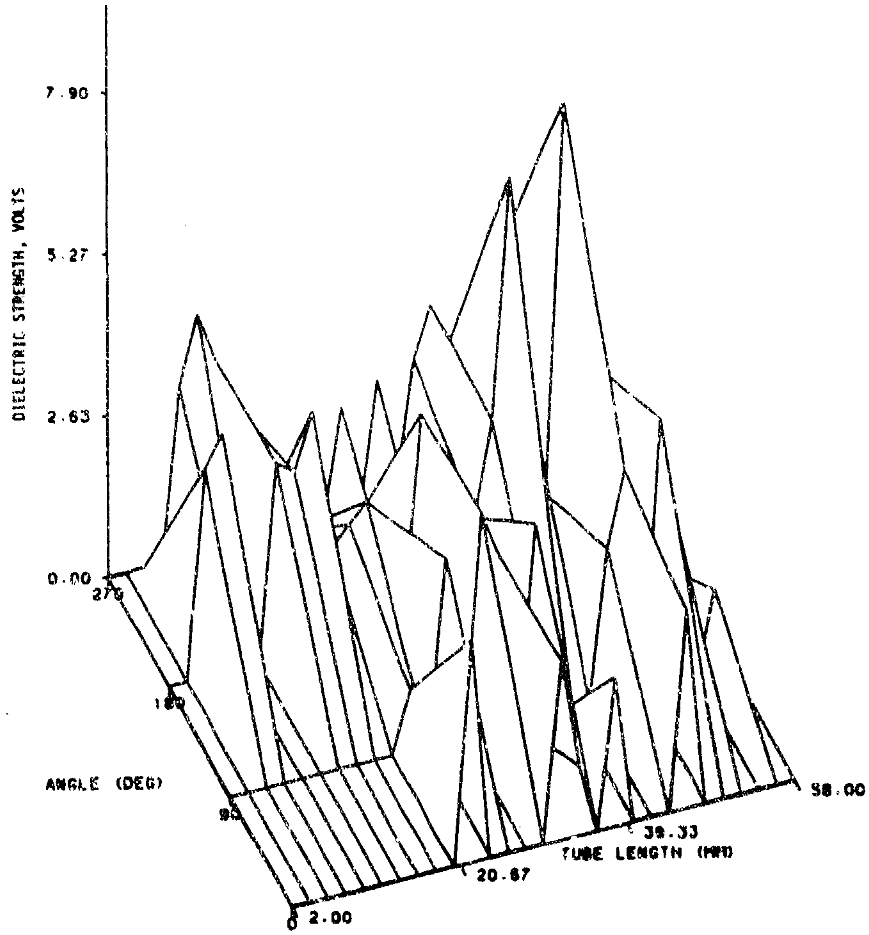
$$V_D = V_{T+D} - V_T.$$

Table 1 lists the calculated deposit volumes for the 21 tests. It is emphasized that this is a very crude approximation to the true deposit volume.

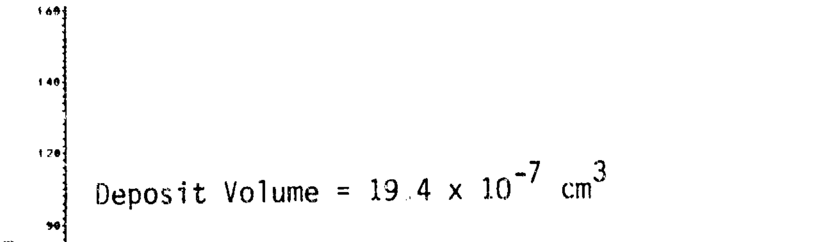
All calculations and graphs were generated using SAS and SAS/GRAPH Version 82.3.

TABLE 1. VOLUME OF DEPOSIT BASED ON THE DIELECTRIC AVERAGE

Fuel	(Code)	Test No.	Temp °C (°F)	Volume of Deposit, $cm^2 X 10^{-7}$
1% S	(AL-13619-F)	521J	177 (350)	19.4
		503J	204 (400)	137.5
		524T	281 (425)	482.9
		520T	232 (450)	1021.3
		418J	260 (500)	3267.6
Cat 1-H	(AL-13618-F)	508J	204 (400)	5.8
		506T	218 (425)	26.4
		498T	232 (450)	40.5
		510T	260 (500)	128.4
		497J	274 (525)	217.9
Diesel Control	(AL-13630-F)	2	273 (525)	26.1
		1	288 (550)	106.0
Jet A-1	(AL-13623-T)	532T	281 (538)	2.7
		538J	288 (550)	17.2
		536J	302 (575)	575.3
Jet A-1 plus Tetralin	(AL-13633-T)	543J	260 (550)	218.7
Jet A-1 plus Tetralin plus Thiophene	(AL-13636-T)	564J	260 (500)	4.7
		574J	274 (525)	25.9
		566J	281 (538)	135.8
		577J	288 (550)	286.7
		570J	302 (575)	897.7

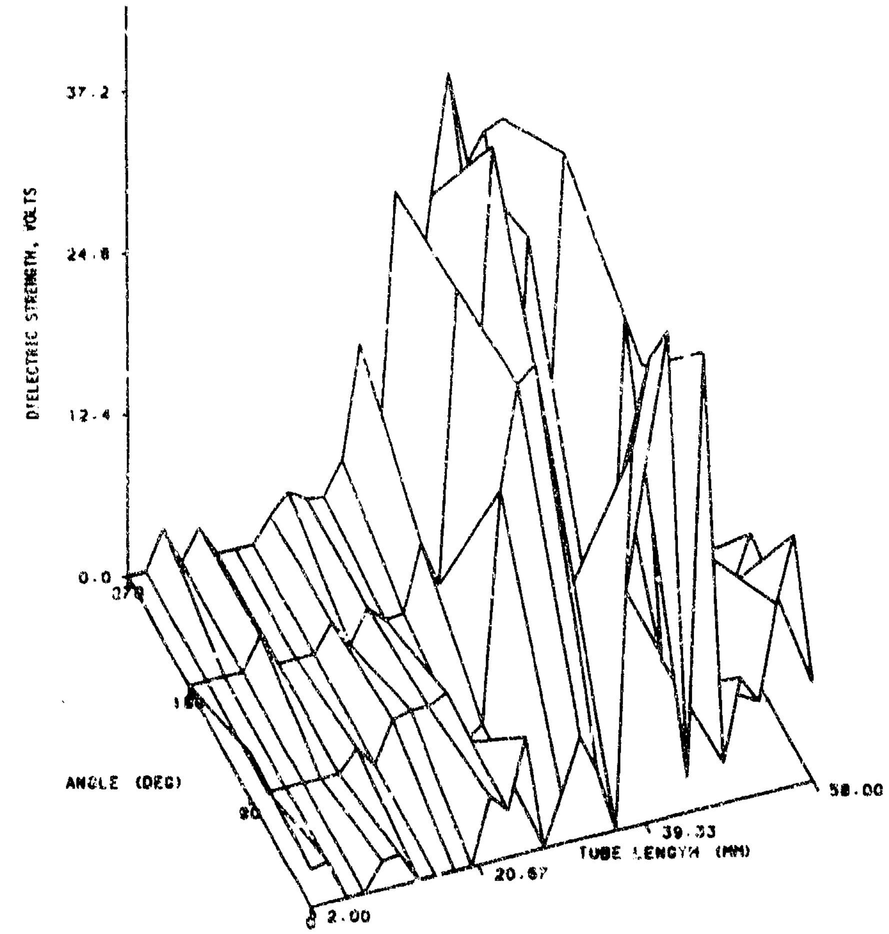


a. Dielectric Strength By Angle By Tube Length

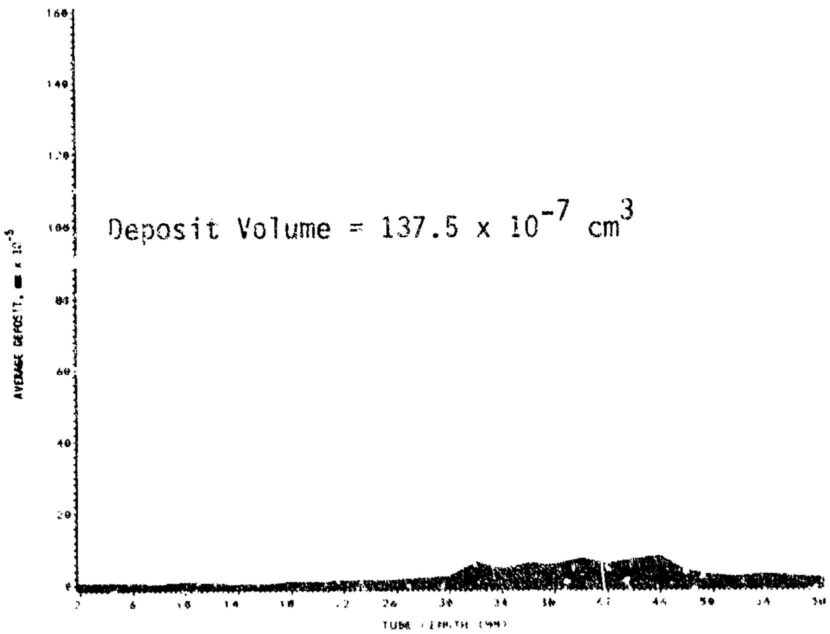


b. Area Plot For Tube Deposit

FIGURE D-1. TEST 521J USING 1% SULFUR REFEREE DIESEL FUEL (AL-13619-F) AT 177°C (350°F)

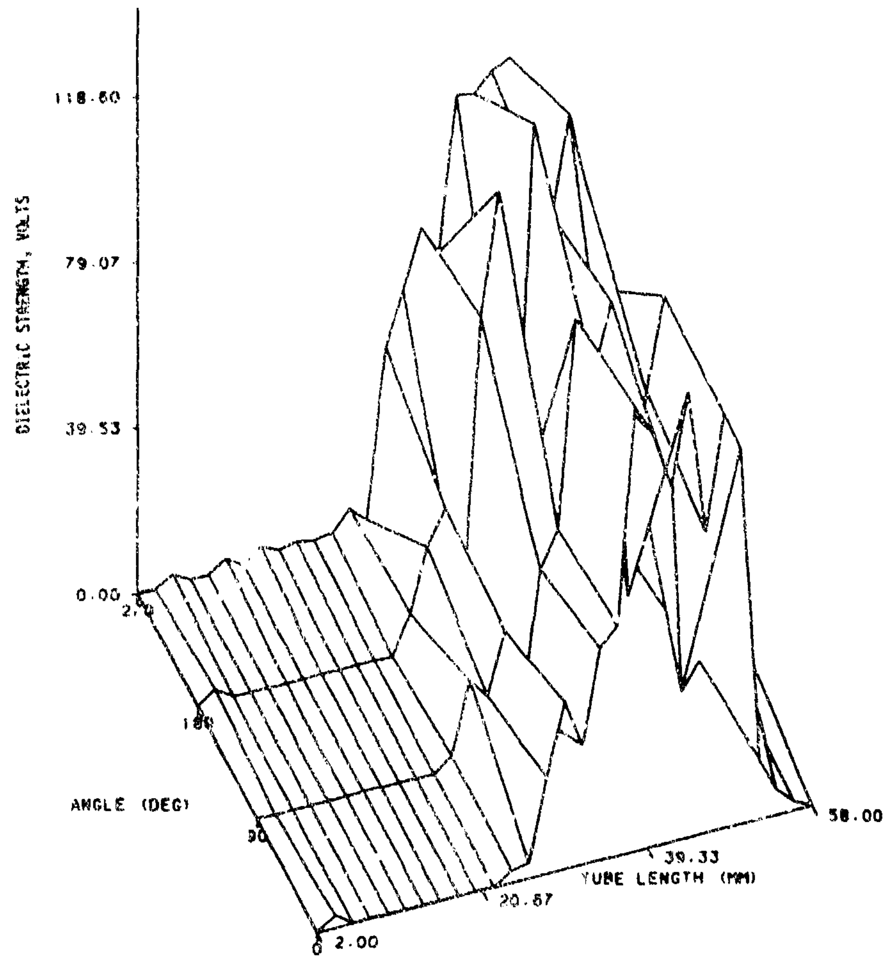


a. Dielectric Strength By Angle By Tube Length

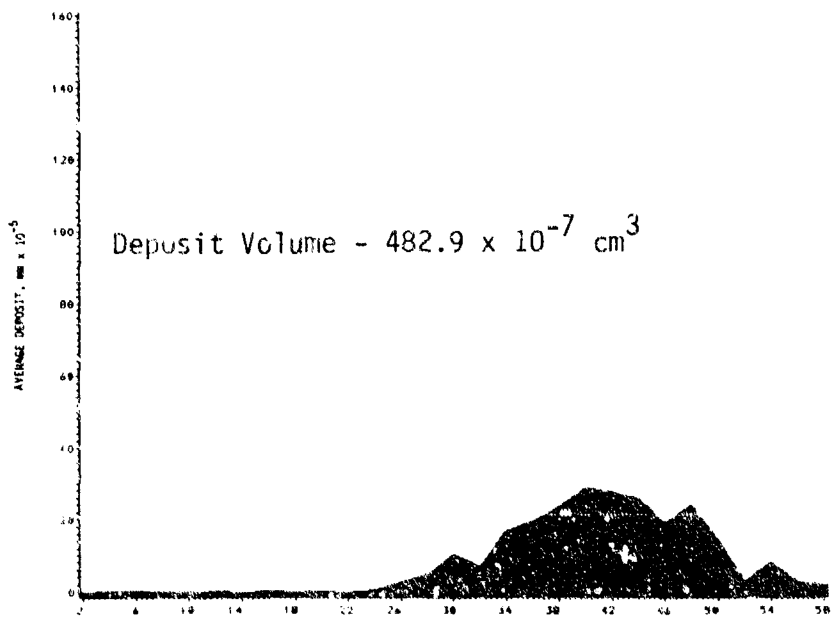


b. Area Plot For Tube Deposit

FIGURE D-2. TEST 5035 USING 1% SULFUR REFEREE DIESEL FUEL (AL-13619-F) AT 204°C (400°F)

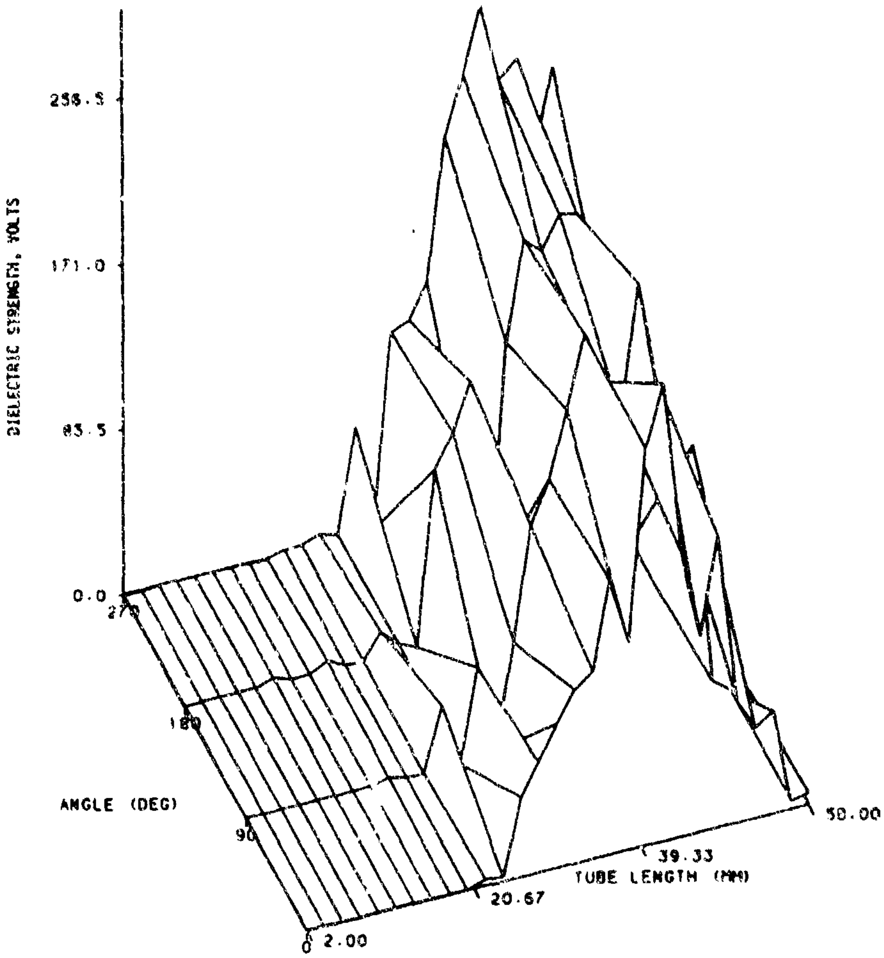


a. Dielectric Strength By Angle By Tube Length

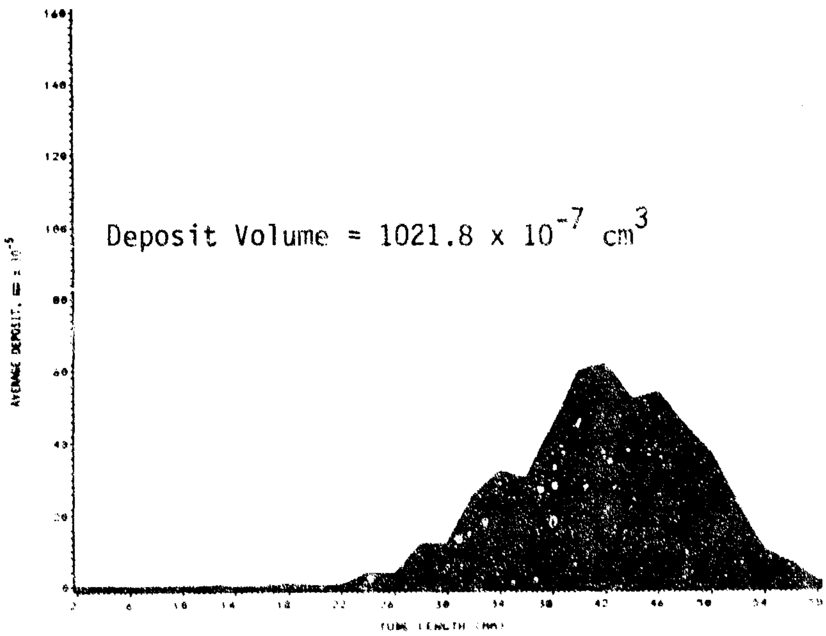


b. Area Plot For Tube Deposit

FIGURE D-3. TEST 524T USING 1% SULFUR REFEREE DIESEL FUEL (AL-13619-F) AT 218°C (425°F)

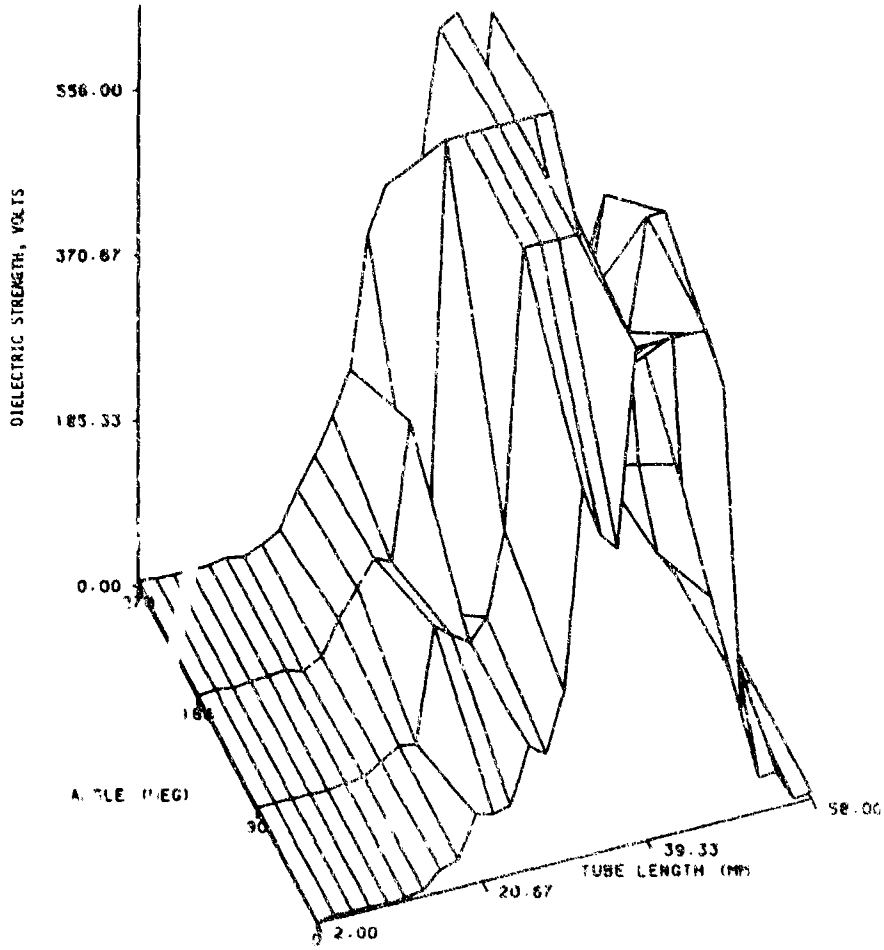


a. Dielectric Strength By Angle By Tube Length

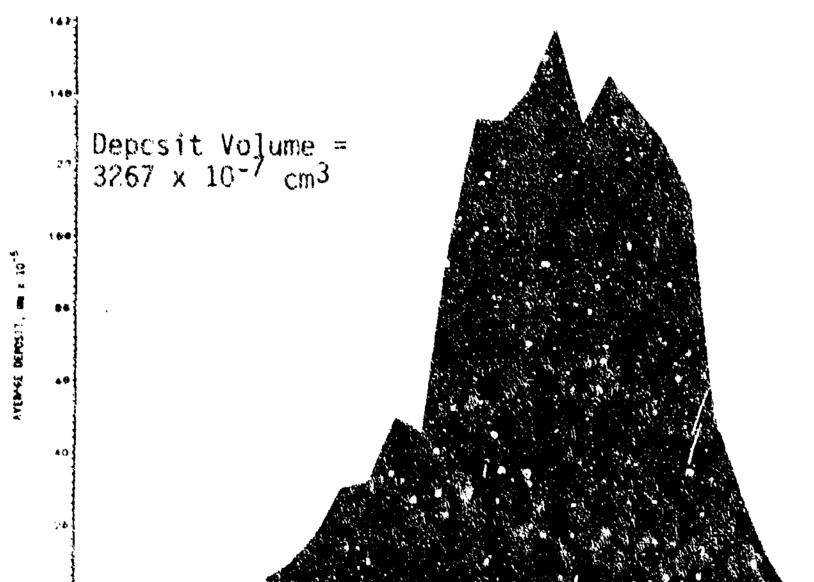


b. Area Plot For Tube Deposit Test

FIGURE D-4. TEST 520T USING 1% SULFUR REFEREE DIESEL FUEL (AL-13619-F) AT 232°C (450°F)

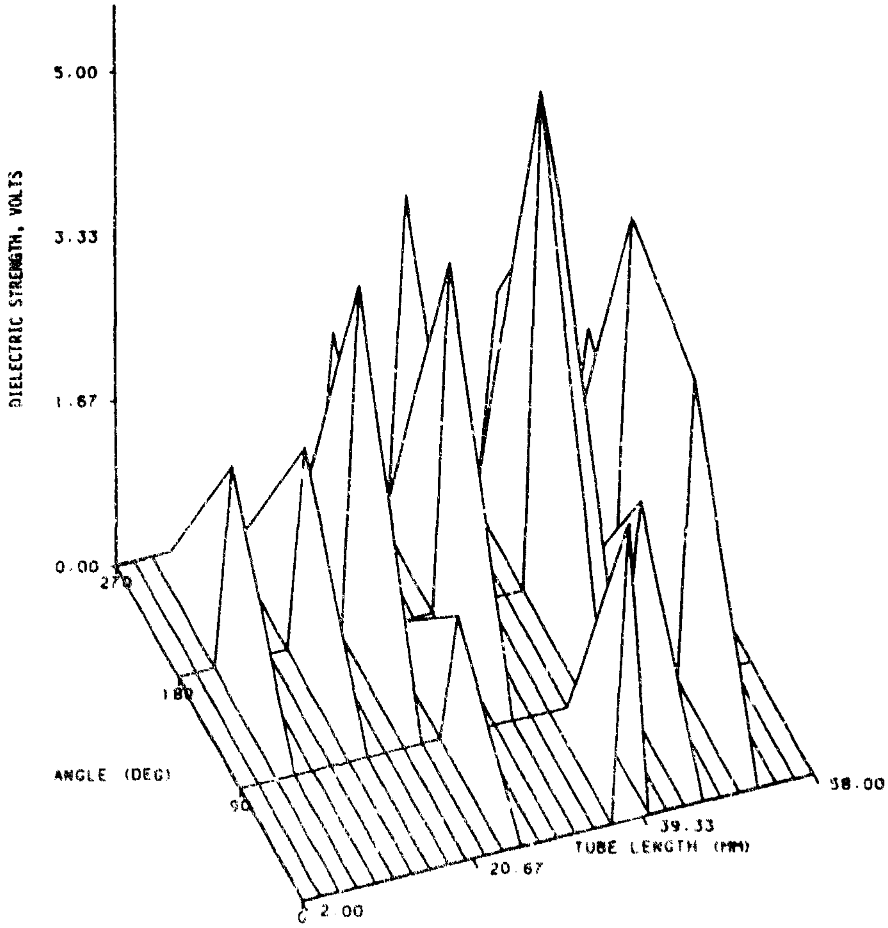


a. Dielectric Strength By Angle By Tube Length

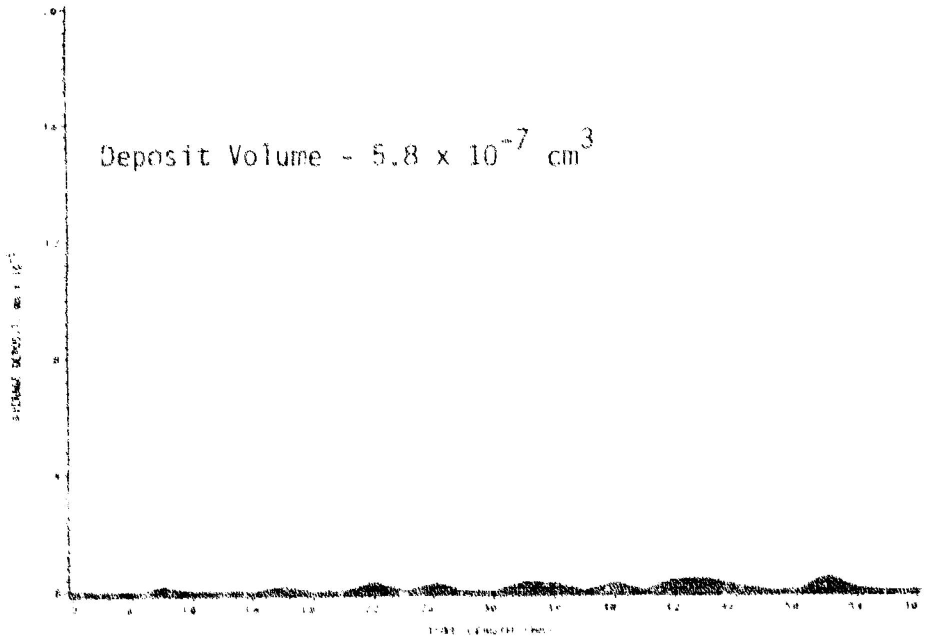


b. Area Plot For Tube Deposit

FIGURE D-5. TEST 418J USING 1% SULFUR REFEREE DIESEL FUEL (AL-1 619-F) AT 260°C (500°F)

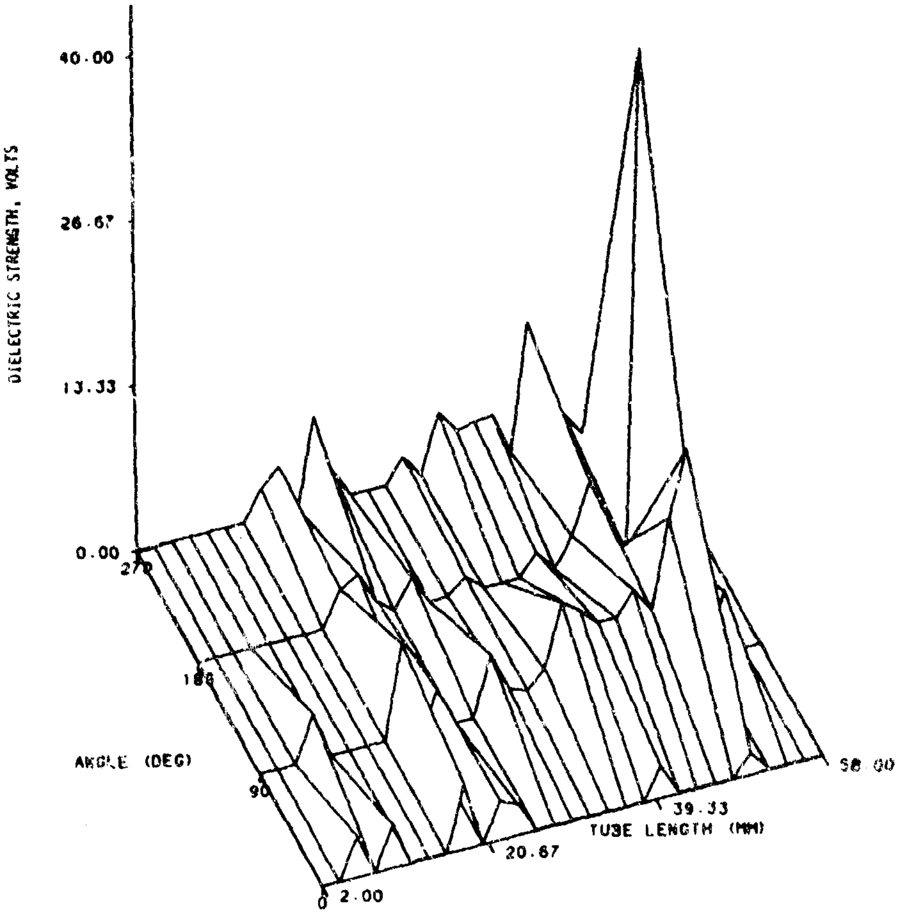


a. Dielectric Strength By Angle By Tube Length

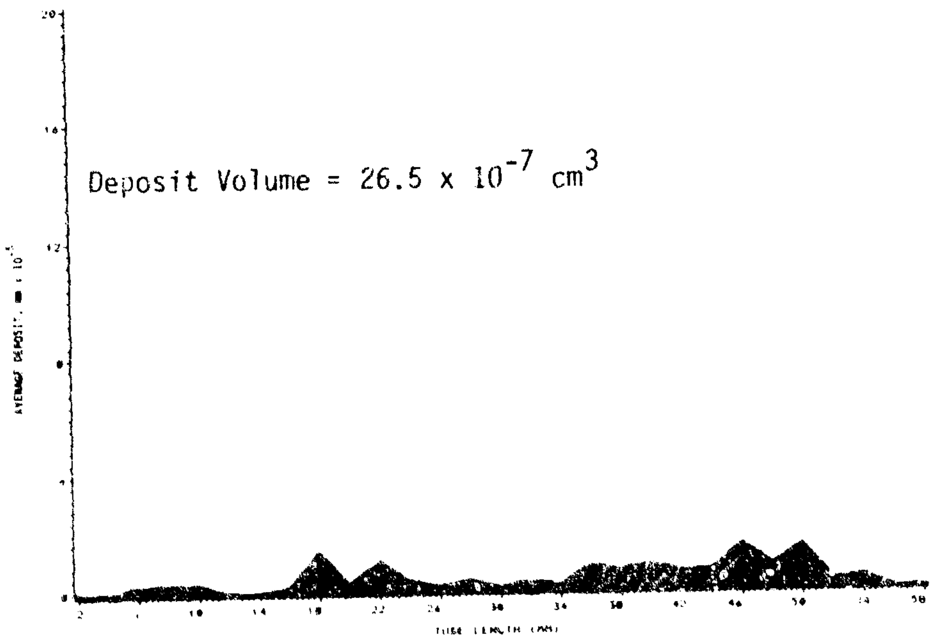


b. Area Plot For Tube Deposit

FIGURE -6. TEST 508J USING CAT I-H (AL-13618-F) AT 204°C (400°C)

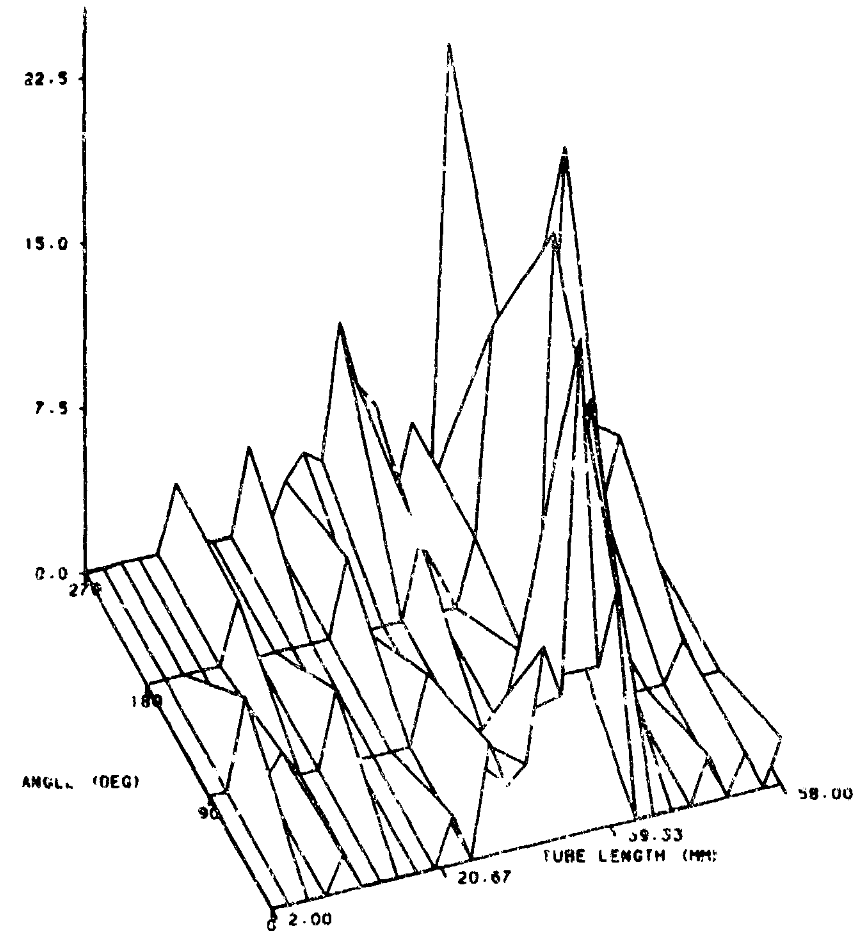


a. Dielectric Strength By Angle By Tube Length

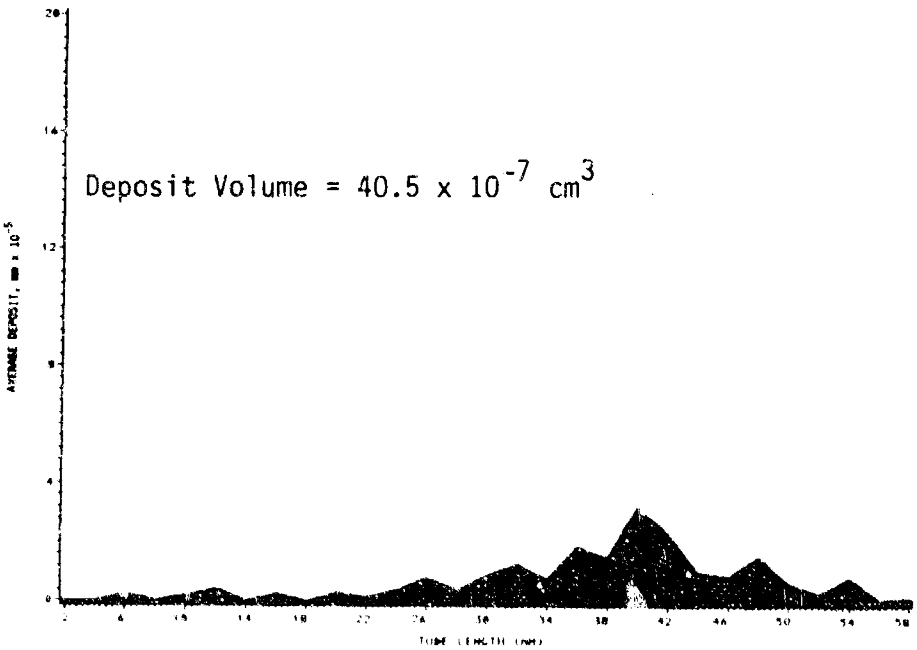


b. Area Plot For Tube Deposit

FIGURE D-7. TEST 506T USING CAT 1-H (AL-13618-F) AT 218°C (425°F)

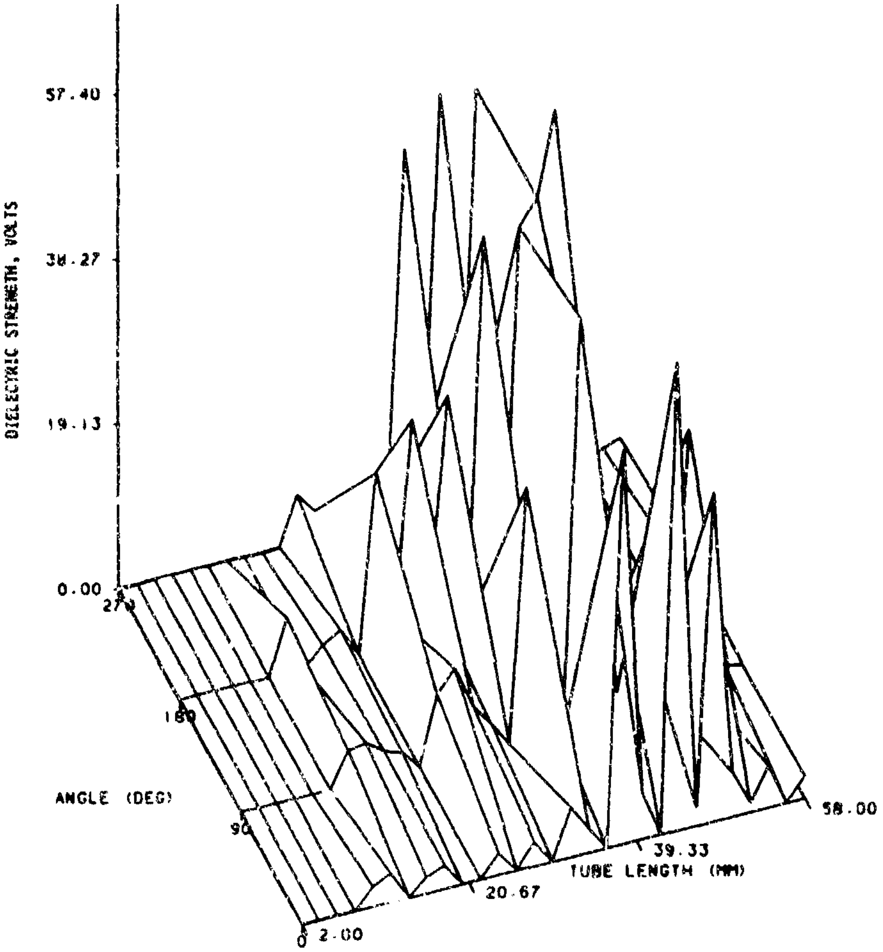


a. Dielectric Strength By Angle By Tube Length

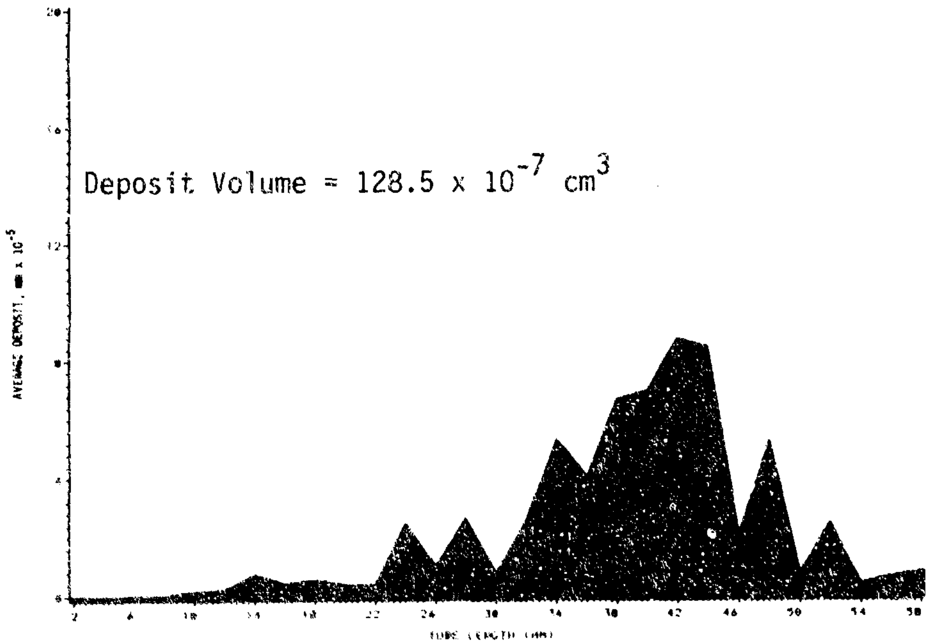


b. Area Plot For Tube Deposit

FIGURE D-8. TEST 498T USING CAT 1-H (AL-13618-F) AT 232°C (450°F)

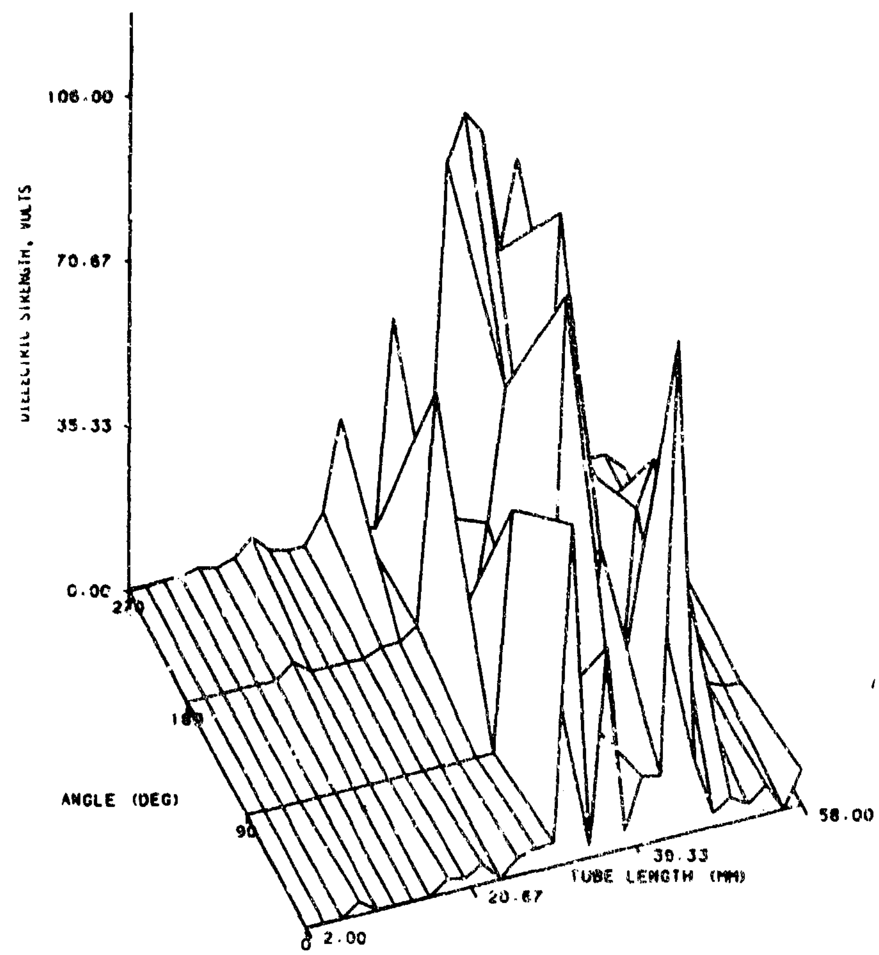


a. Dielectric Strength By Angle By Tube Length

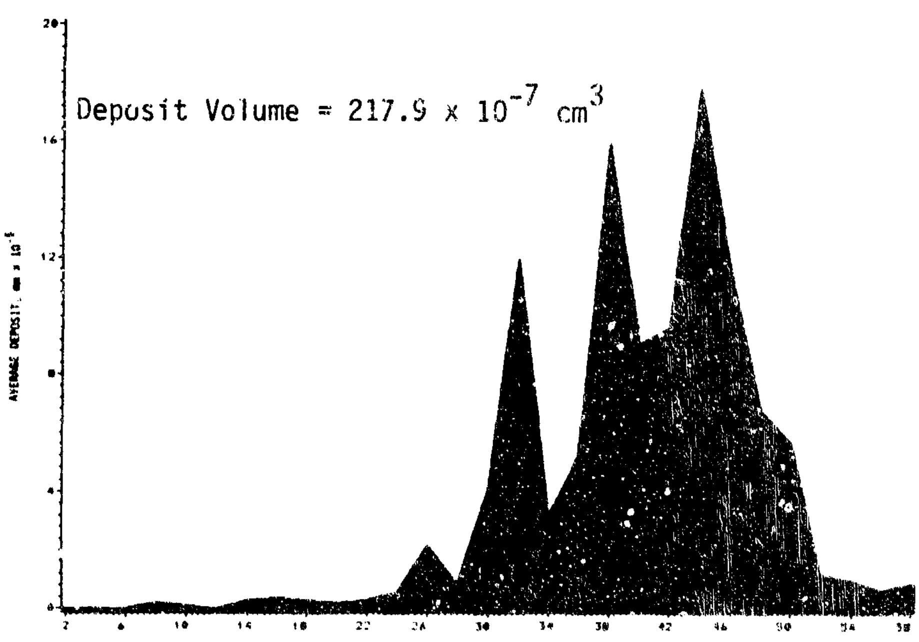


b. Area Plot For Tube Deposit

FIGURE D-9. TEST 510T USING CAT 1-H (AL-13618-F) AT 260°C (500°F)

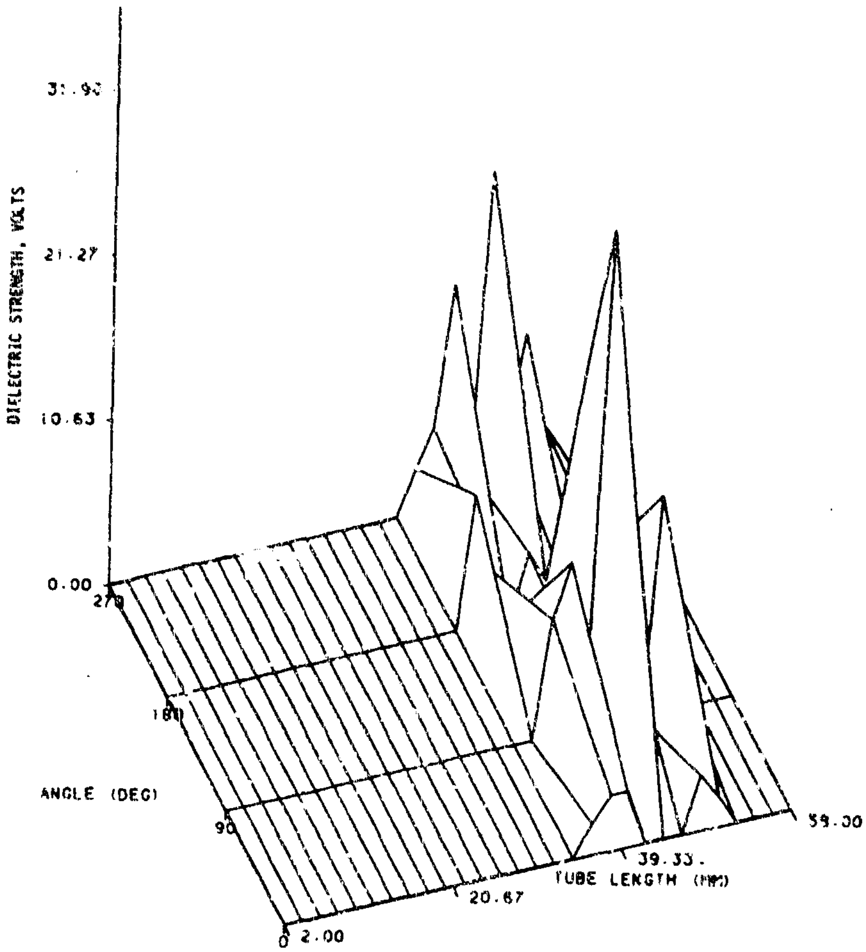


a. Dielectric Strength By Angle By Tube Length

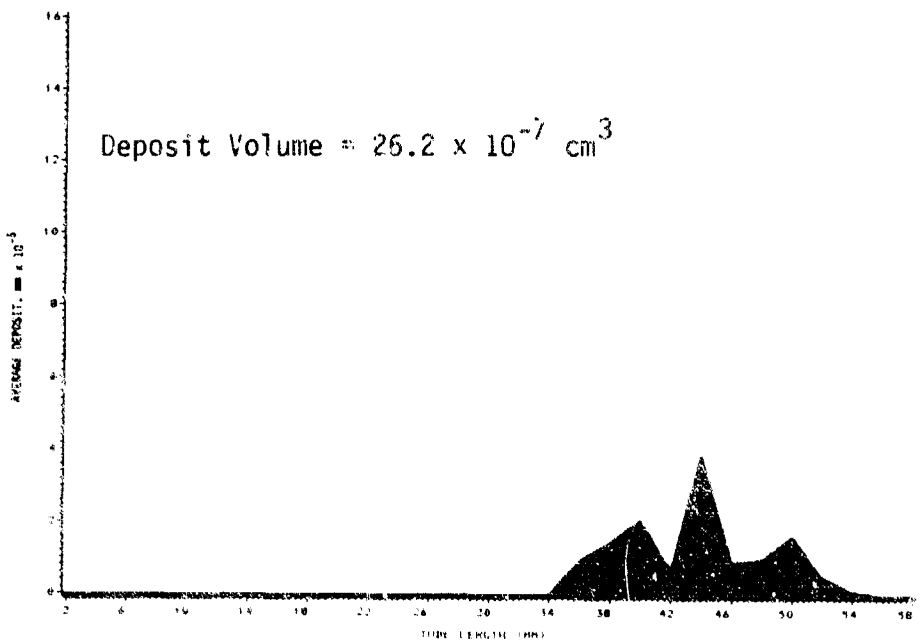


b. Area Plot For Tube Deposit

FIGURE D-10. TEST 497J USING CAT 1-H (AC-13618F) AT 279°C (525°F)

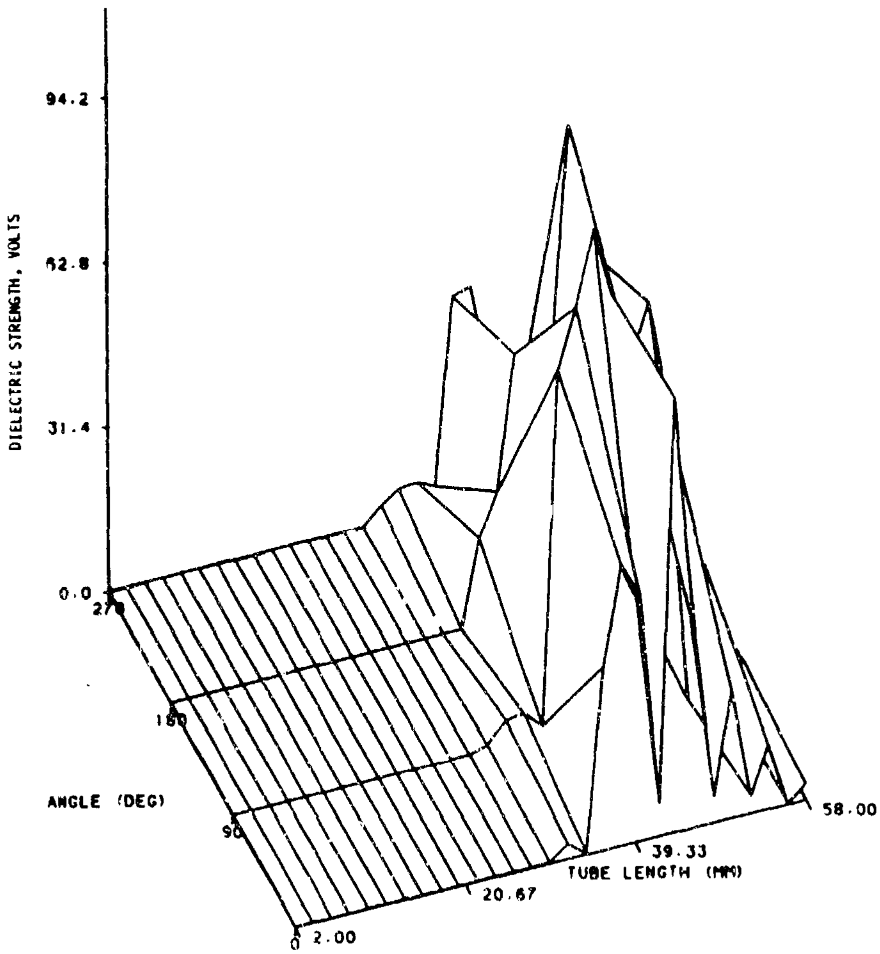


a. Dielectric Strength By Angle By Tube Length

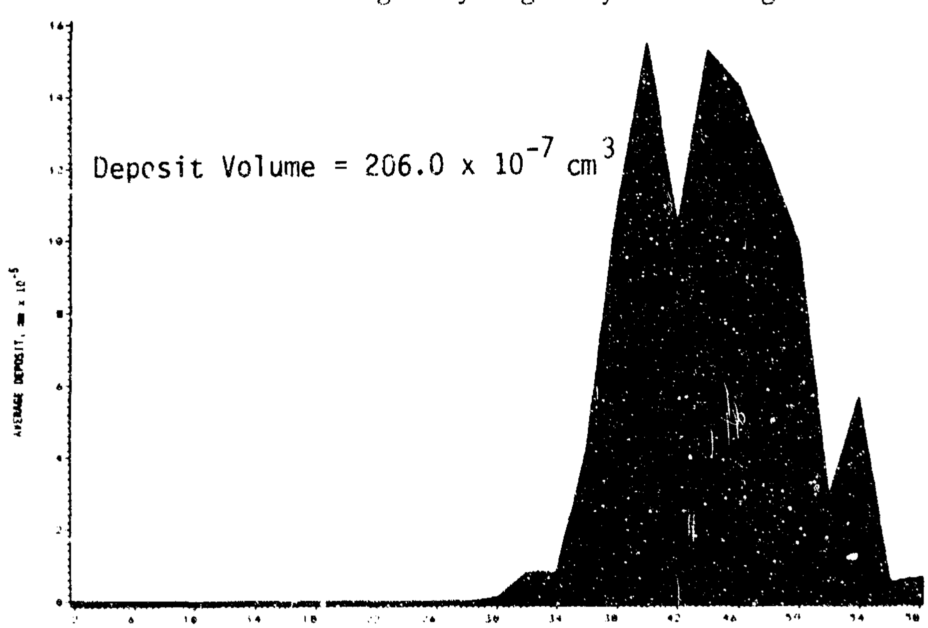


b. Area Plot For Tube Deposit

FIGURE D-11. TEST 2 USING DIESEL CONTROL (AL-13630-F) AT 274°C (525°F)

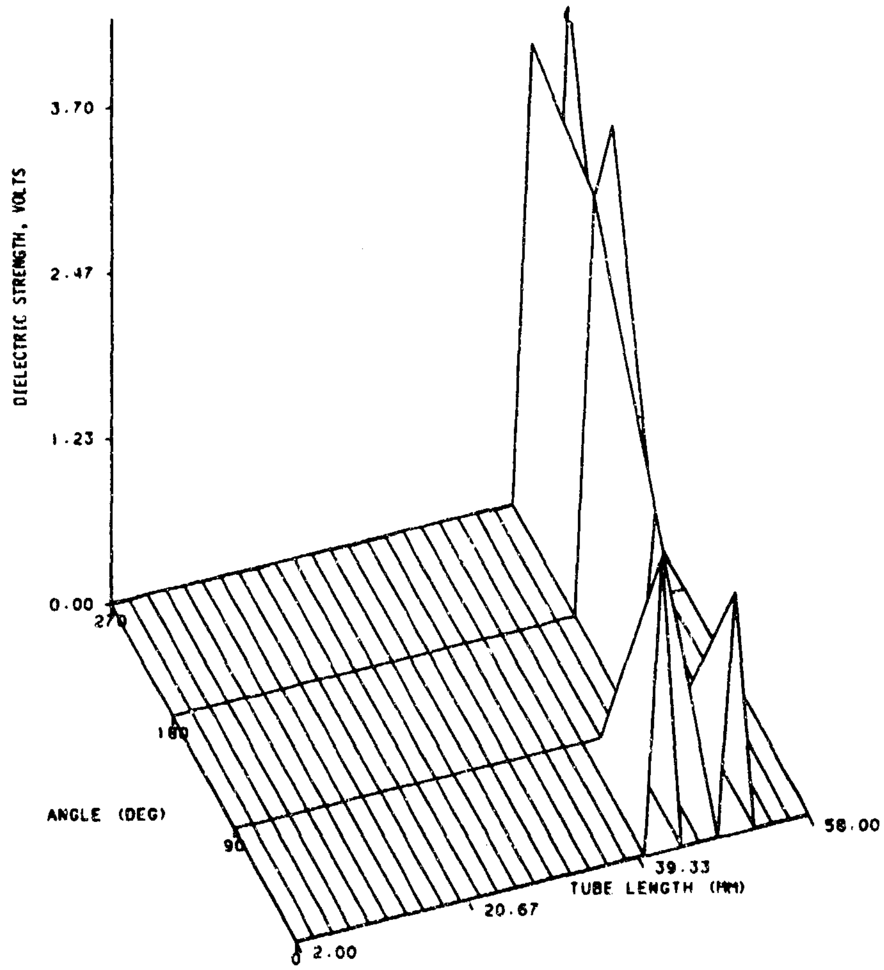


a. Dielectric Strength By Angle By Tube Length

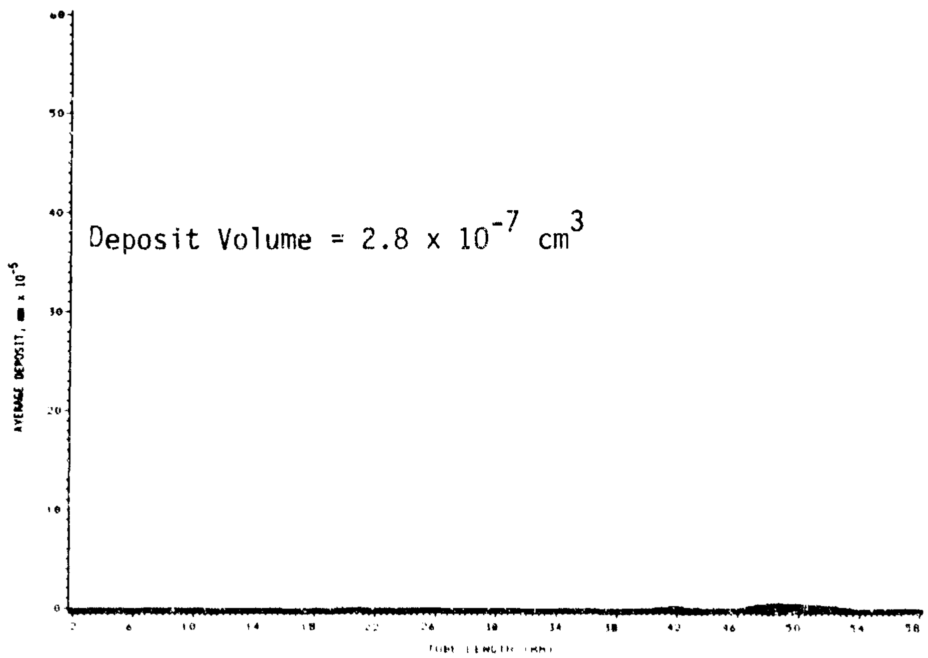


b. Area Plot For Tube Deposit

FIGURE D-12. TEST 1 USING DIESEL CONTROL (AL-13630-F) AT 288°C (550°F)

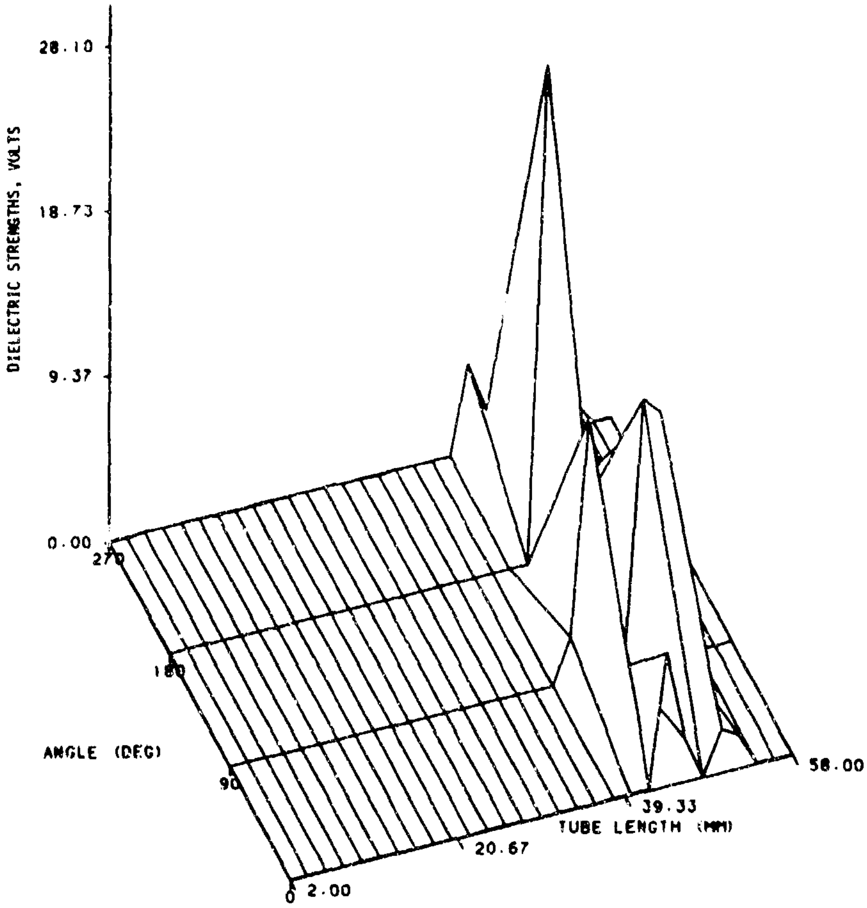


a. Dielectric Strength By Angle By Tube Length

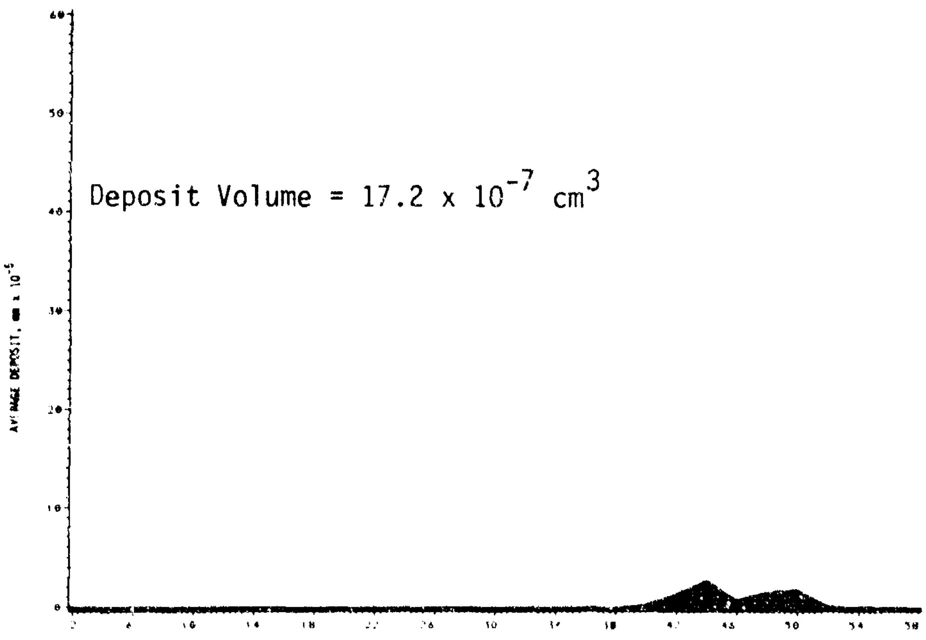


b. Area Plot For Tube Deposit

FIGURE D-13. TEST 532T USING JET A-1 (AL-13623-T) AT 281°C (538°F)

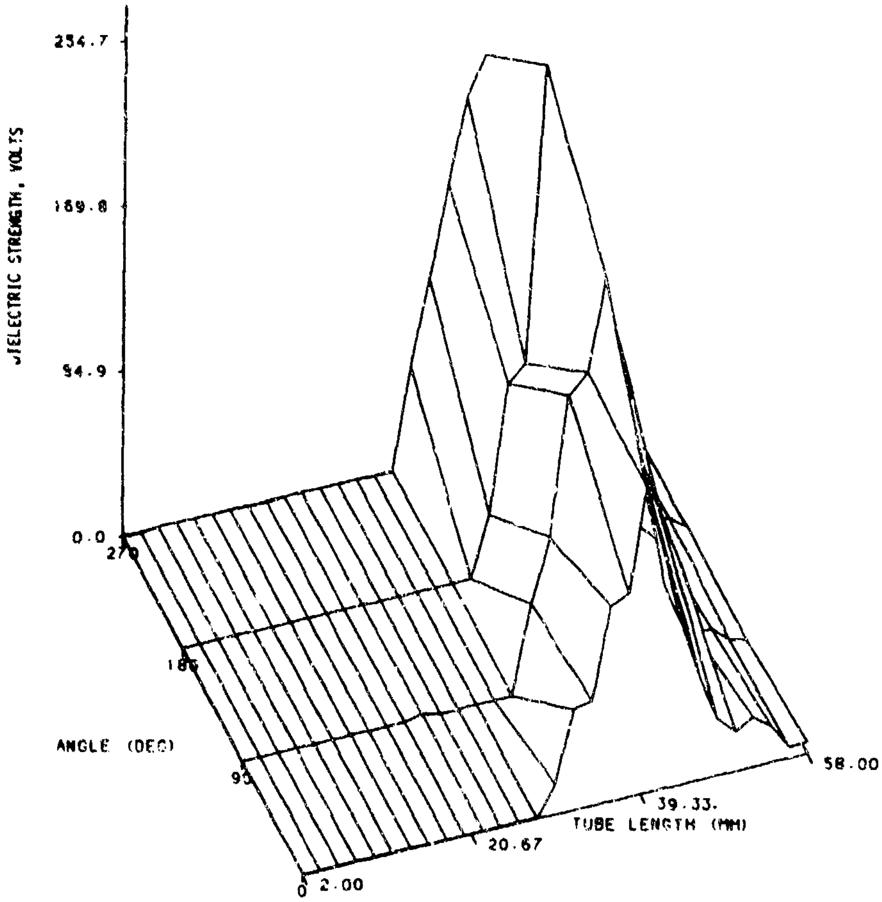


a. Dielectric Strength By Angle By Tube Length

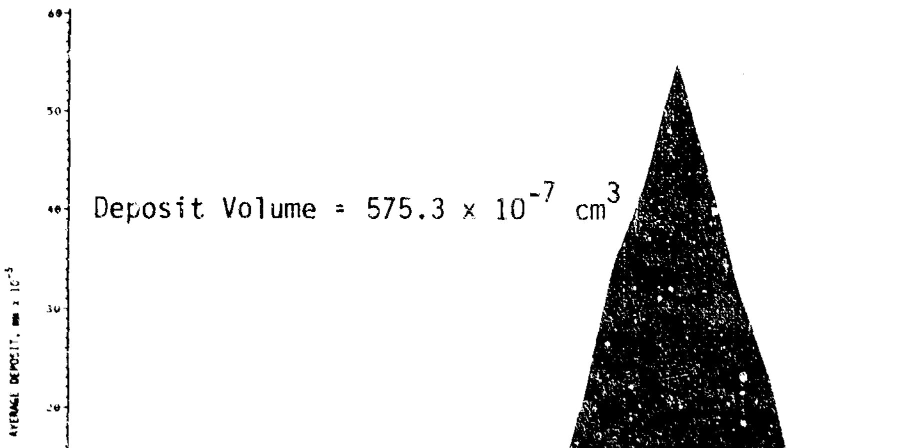


b. Area Plot For Tube Deposit

FIGURE D-14. TEST 538J USING JET A-1 (AL-13623-T) at 288°C (550°F)

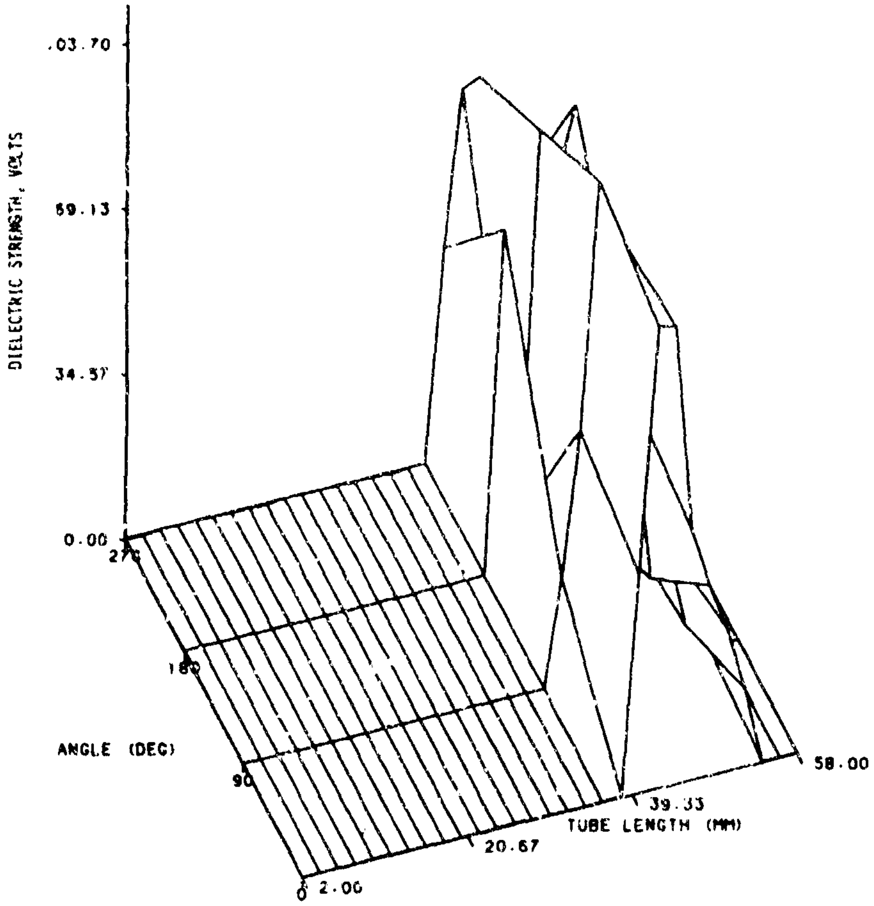


a. Dielectric Strength By Angle By Tube Length

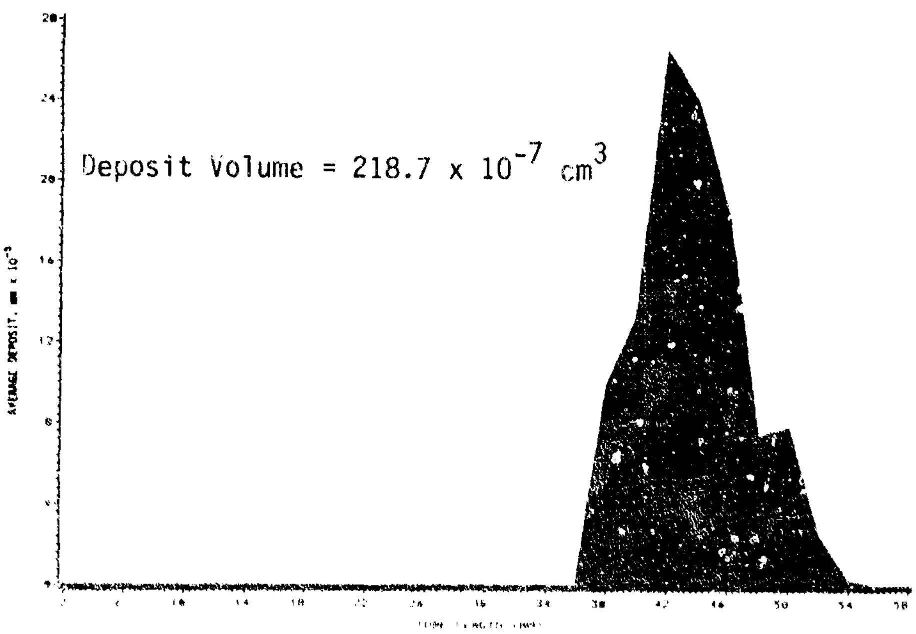


b. Area Plot For Tube Deposit

FIGURE D-15. TEST 536J USING JET A-1 (AL-12623-T) AT 302°C (575°F)

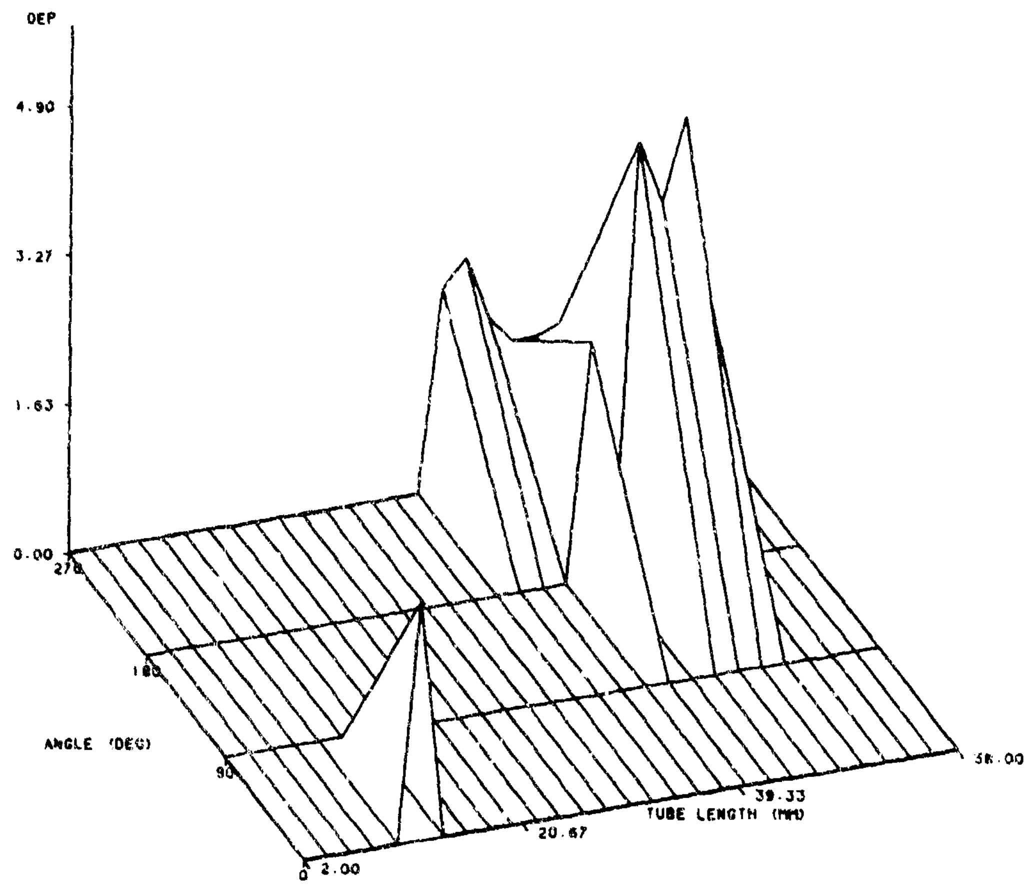


a. Dielectric Strength By Angle By Tube Length

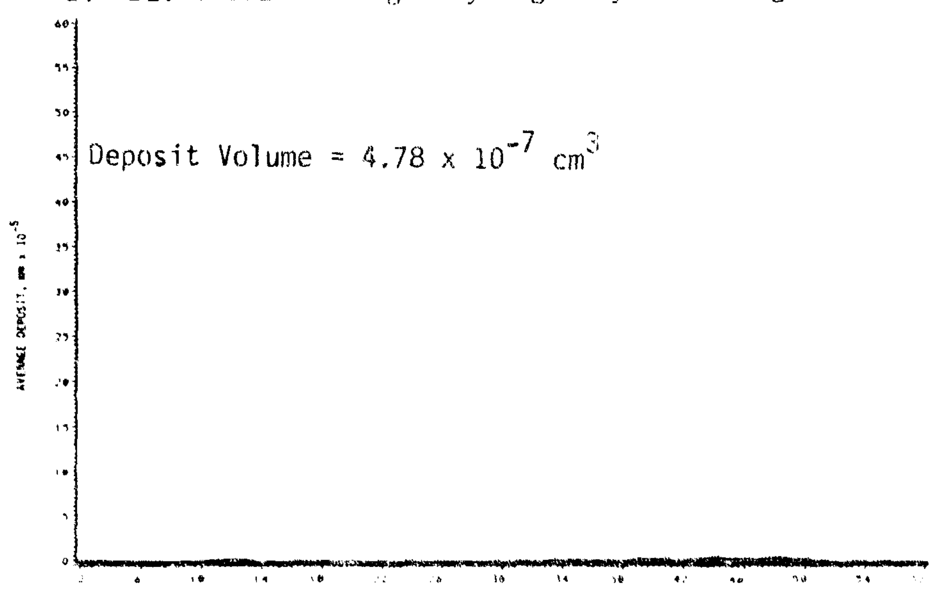


b. Area Plot For Tube Deposit

FIGURE D-16. TEST 543J USING JET A-1 WITH TETRALIN (5%) AT 288°C (550°F)

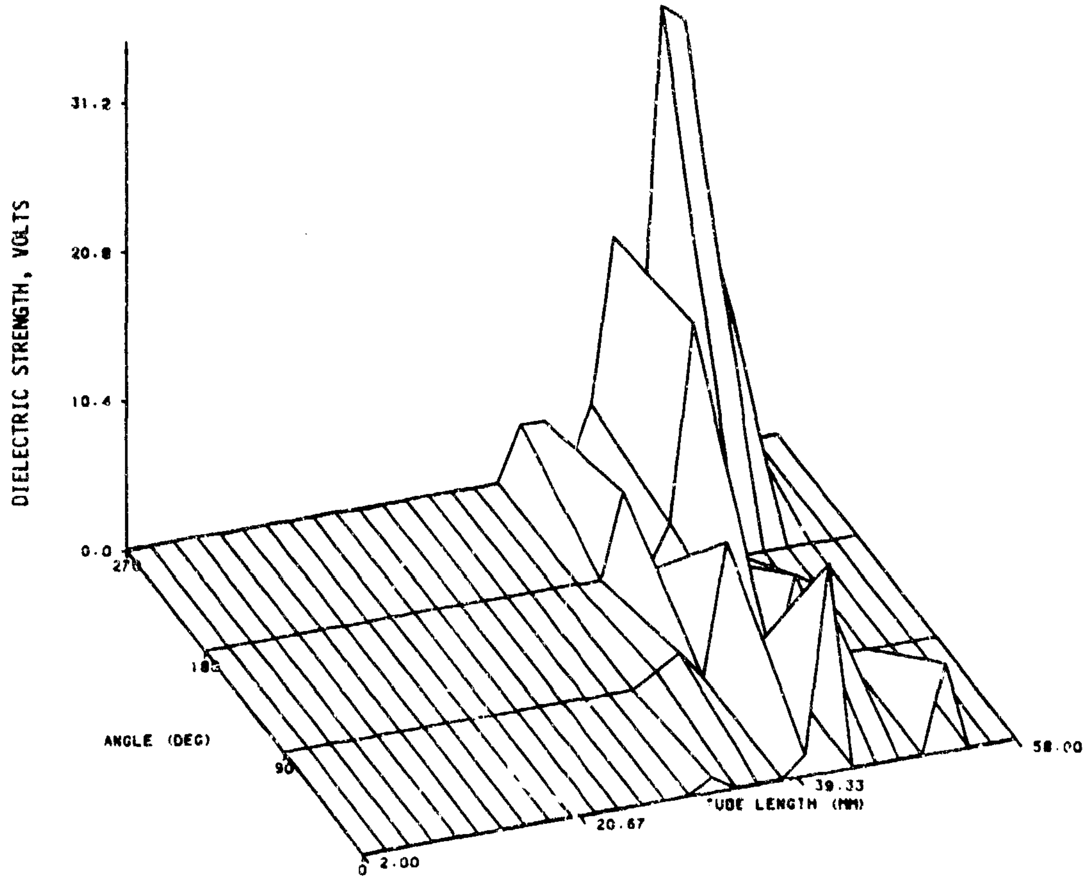


a. Dielectric Strength By Angle By Tube Length

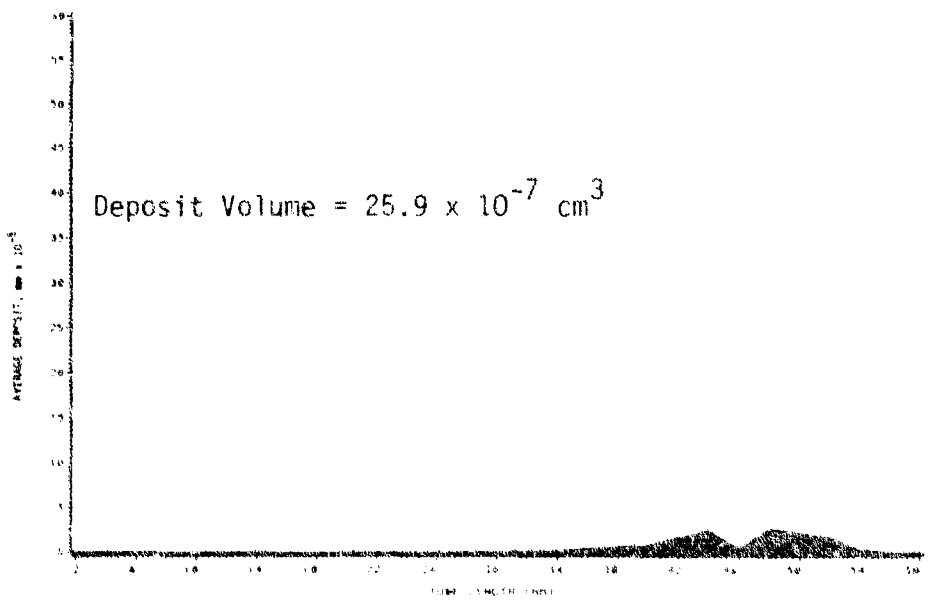


b. Area Plot For Tube Deposit

FIGURE D-17. TEST 564J USING JET A-1 WITH THIOPHENE AND TETRALIN AT 260°C (500°F)

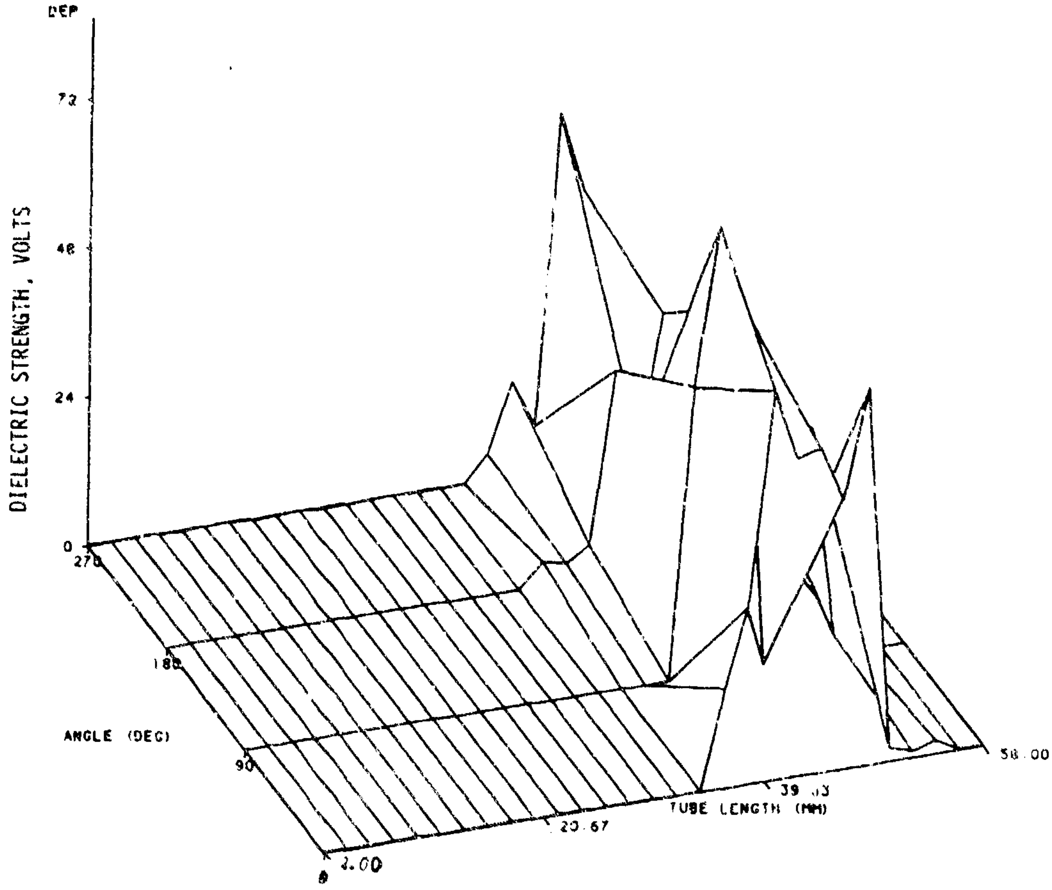


a. Dielectric Strength By Angle By Tube Length

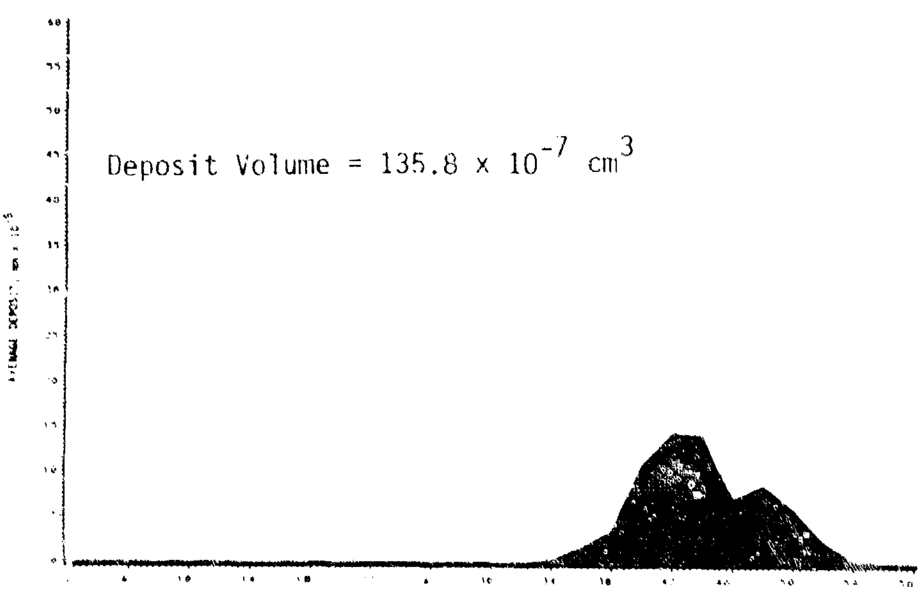


b. Area Plot For Tube Deposit Test

FIGURE D-18. TEST 574J USING JET A-1 WITH THIOPHENE AND TETRALIN AT 274°C (525°F)

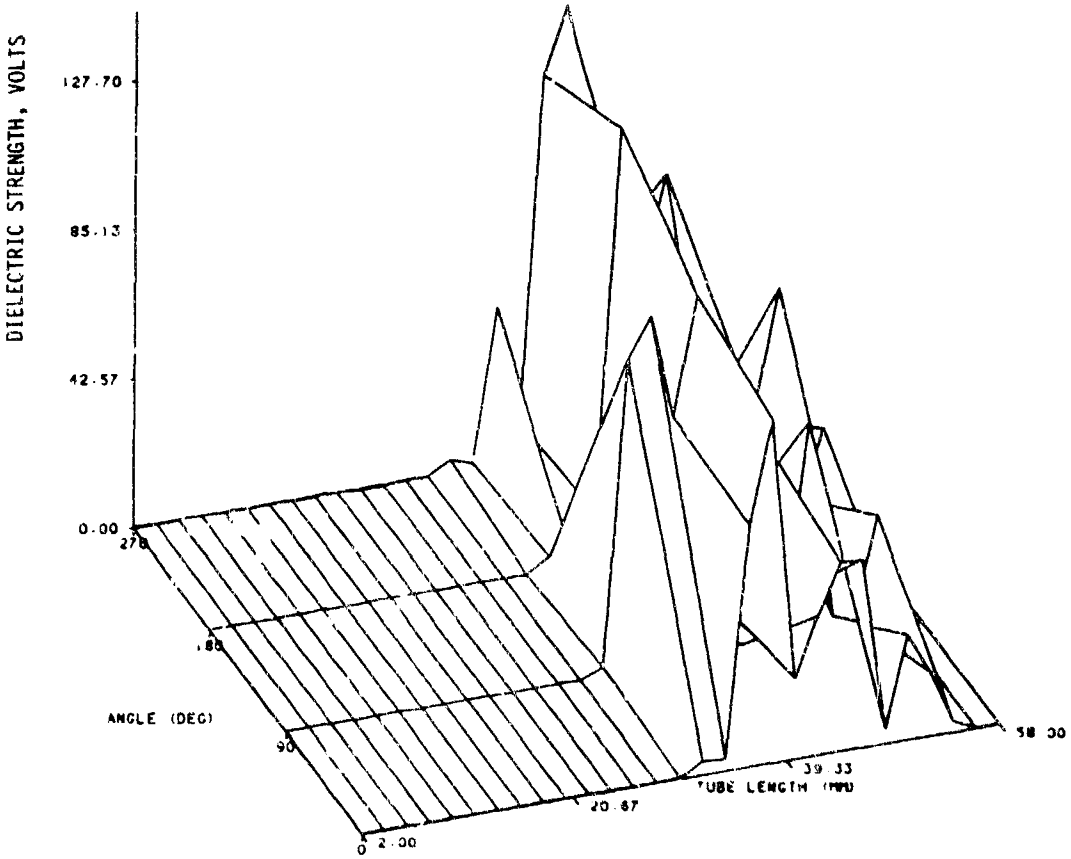


a. Dielectric Strength By Angle By Tube Length

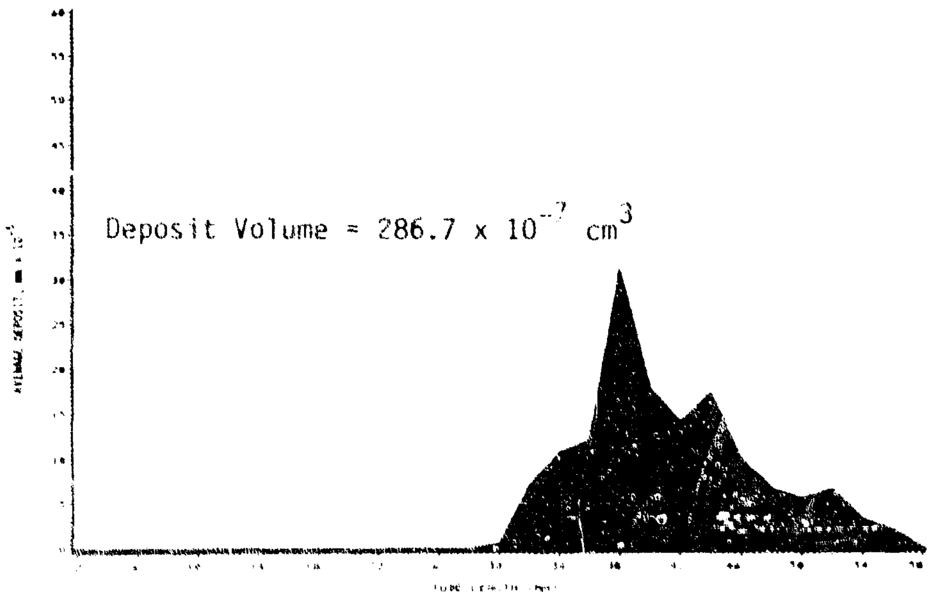


b. Area Plot For Tube Deposit

FIGURE D-19. TEST 5663 USING JET A-1 WITH THIOPHENE AND TETRALIN AT 281°C (538°F)

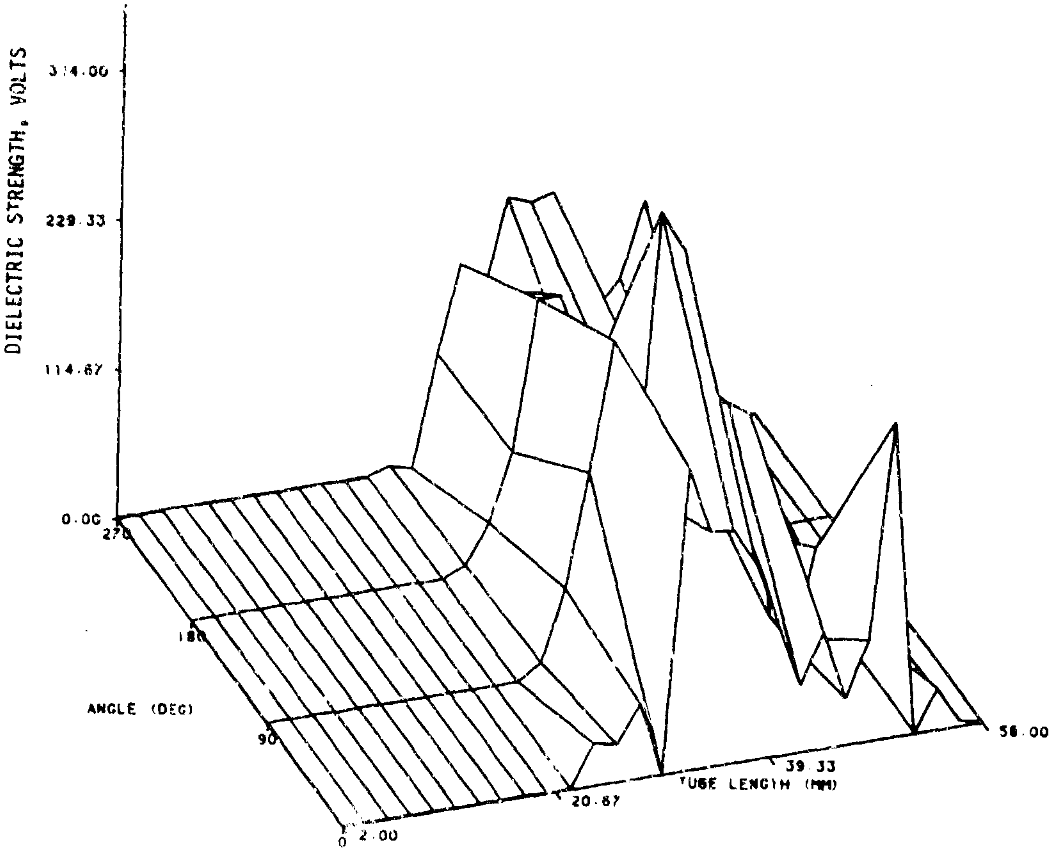


a. Dielectric Strength By Angle By Tube Length

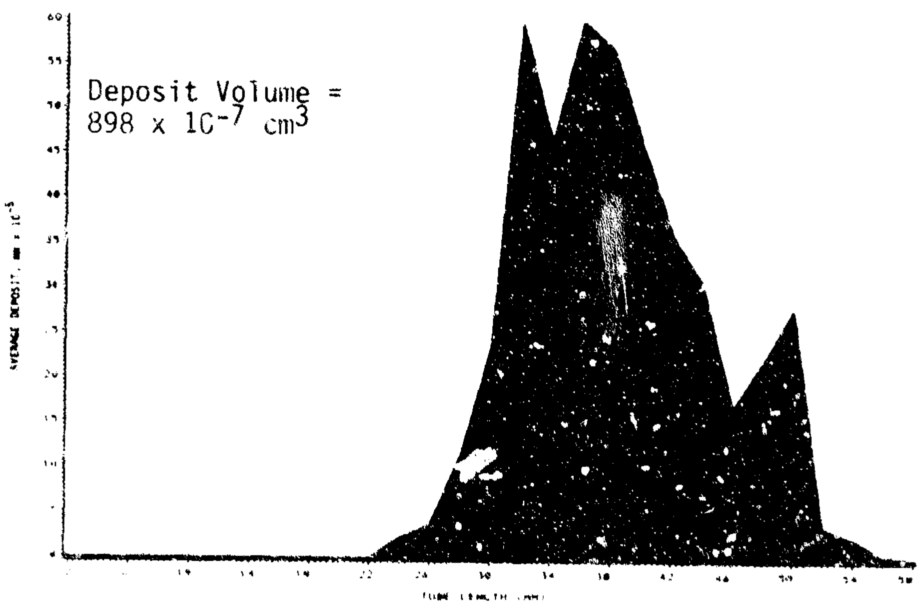


b. Area Plot For Tube Deposit

FIGURE B-20. TEST 577J USING JET A-1 THIOPHENE AND TETRALIN AT 288°C (550°F)



a. Dielectric Strength By Angle By Tube Length



b. Area Plot For Tube Deposit

FIGURE D-21. TEST 5703 USING JET A-1 WITH THIOPENE AND TETRALIN AT 302°C (575°F)

APPENDIX E

STAINLESS STEEL VERSUS ALUMINUM JFTOT DATA

CAT 1-H AL-13618-F at 232°C (450°F) With Stainless Steel Heater Tube - Test 1*

Tube Station	Dielectric Strength, Volts					Mark 9 TDR	Visual Rating
	0°	90°	180°	270°	Dielectric Average		
02	2.8	2.0	0.2	0.5	1.4	[illegible]	0
04	3.2	0.8	0.5	0.2	1.2	8	0
06	0.4	1.2	0.3	0.3	0.6	7	0
08	0.3	1.3	0.8	1.0	0.8	6	0
10	4.0	0.8	0.4	0.1	1.3	6	0
12	0.6	4.3	1.4	0.8	1.8	7	0
14	0.4	2.2	1.1	5.3	2.2	8	0
16	0.9	0.9	1.3	4.6	1.9	9	1
18	3.8	0.2	2.0	0.2	1.5	10	1
20	0.9	0.9	0.3	4.1	1.6	11	A**
22	1.8	5.9	0.9	4.5	3.3	12	A
24	0.9	0.5	0.4	3.1	1.2	13	A
26	0.2	5.1	1.2	1.3	1.9	15	A
28	1.0	0.1	1.0	4.4	1.6	16	A
30	4.6	5.0	0.8	3.5	3.5	17	A
32	4.6	3.8	0.9	6.4	3.9	18	A
34	5.1	1.7	0.5	1.2	2.1	20	A
36	0.4	0.1	0.1	1.8	0.6	23	A
38	0.2	7.2	0.8	4.9	3.2	25	A
40	2.3	0.3	1.1	12.5	4.0	28	3
42	1.2	5.3	0.4	1.9	2.2	27	4
44	6.9	5.1	3.8	1.4	4.3	24	4
46	5.1	4.6	4.4	1.2	3.9	18	4
48	6.2	3.3	0.4	0.7	4.2	17	A
50	5.8	3.8	11.9	3.8	6.3	18	A
52	13.2	8.2	6.0	0.7	7.0	17	A
54	4.9	1.0	12.6	0.4	4.8	17	A
56	6.7	3.5	5.9	4.9	5.2	17	A
58	6.8	0.1	3.4	5.0	3.8	23	A
TOTAL	93.4	79.0	64.5	80.6	81.3		

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 0
Preheater Deposit Code: >4
TDR Spun Deposit Rating: 28 at 40

**A = Abnormal Deposit Color

CAT 1-H AL-13618-F at 232°C (450°F) With Stainless Steel Heater Tube - Test 2*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	Mark 9 TDR	Visual Rating
02	0.5	0.6	2.9	1.3	1.3	11	1
04	0.6	0.1	0.7	1.3	0.7	9	1
06	0.6	1.1	1.0	0.1	0.7	8	1
08	0.7	1.4	1.4	0.1	0.9	8	1
10	4.3	0.3	8.3	1.9	3.7	8	1
12	1.8	0.1	1.5	0.7	1.0	8	1
14	1.1	0.1	0.9	2.5	1.2	9	1
16	2.9	0.8	0.6	0.8	1.3	10	1
18	1.9	4.3	1.6	0.7	2.1	10	A**
20	1.6	4.3	1.5	3.6	2.7	12	A
22	0.7	2.7	0.6	5.0	2.2	13	A
24	1.6	3.7	0.8	0.1	1.5	13	A
26	2.5	5.2	4.8	0.4	3.2	15	A
28	1.5	5.0	3.2	2.5	3.0	16	A
30	3.8	3.1	2.6	4.0	3.4	18	2
32	1.5	4.0	4.7	2.7	3.2	19	2
34	0.1	0.7	5.7	1.3	2.0	20	2
36	4.6	0.5	5.2	5.2	3.9	24	3
38	7.5	4.3	5.1	5.7	5.7	27	3
40	0.3	1.7	6.3	5.3	3.4	31	3
42	0.1	1.7	7.9	1.9	2.9	31	4
44	5.4	0.5	4.7	4.2	3.7	28	4
46	6.1	0.5	9.2	4.8	5.2	23	4
48	3.8	1.7	3.8	5.6	3.7	21	4
50	4.2	8.2	2.7	4.4	4.9	20	A
52	4.6	11.5	2.0	0.8	4.7	21	A
54	5.3	13.1	10.6	4.8	8.4	22	A
56	8.7	0.3	0.8	4.4	3.5	27	4
58	5.1	4.4	7.0	4.3	5.2	32	4
TOTAL	83.6	86.0	107.9	80.0	89.3		

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 0
Preheater Deposit Code: >4
TDR Spun Deposit Rating: 26 at 44

**A = Abnormal Deposit Color

CAT 1-H AL-13618-F at 232°C (450°F) With Stainless Steel Heater Tube - Test 3*

Tube Station	Dielectric Strength, Volts					Mark 9 TDR	Visual Rating
	0°	90°	180°	270°	Dielectric Average		
02	3.3	4.9	1.2	0.1	2.5	14	1
04	0.8	0.2	1.2	0.2	0.6	8	0
06	5.2	1.3	0.9	0.3	1.9	7	0
08	3.3	3.2	0.2	0.2	1.7	7	0
10	0.3	5.5	1.6	0.4	1.9	7	0
12	0.4	1.8	0.4	0.1	0.7	7	0
14	0.4	4.9	1.1	0.4	1.7	7	0
16	0.2	2.4	0.3	0.2	0.8	8	0
18	0.1	1.3	0.5	0.3	0.5	9	A**
20	0.3	0.1	1.2	0.3	0.5	10	A
22	0.3	4.6	1.7	0.3	1.7	10	A
24	0.2	0.2	0.3	3.2	1.0	11	A
26	4.9	0.4	0.1	0.3	1.4	12	A
28	0.3	0.1	0.5	0.4	0.3	13	A
30	3.1	0.2	0.5	2.6	1.6	15	A
32	0.1	0.1	5.1	0.4	1.4	16	A
34	0.5	0.5	5.8	1.7	2.1	17	A
36	5.4	0.1	1.7	7.1	3.6	21	A
38	4.5	0.7	3.8	7.6	4.2	24	A
40	8.8	0.4	0.3	10.7	5.0	28	A
42	1.7	0.2	2.9	1.9	1.7	28	3
44	2.3	0.3	5.9	1.5	2.5	25	4
46	0.5	0.1	3.8	12.2	4.2	20	4
48	0.8	0.1	3.4	6.8	2.8	18	A
50	0.7	4.2	1.0	10.2	4.0	18	A
52	9.6	5.6	1.0	6.2	5.6	18	A
54	2.4	7.5	9.9	6.5	6.6	19	A
56	0.7	3.8	8.1	5.5	4.5	23	A
58	2.2	5.1	0.2	1.7	2.3	25	3
TOTAL	63.6	59.9	64.4	89.2	69.3		

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 0
Preheater Deposit Code: >4
TDR Spun Deposit Rating: 28 at 40

**A = Abnormal Deposit Color

Jet A-1 With Tetralin (5%) AL-13633-T at 268°C (515°F)
With Stainless Steel Heater Tube - Test 1*

Tube Location	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	Mark 9 TDR	Visual Rating
02	1.3	1.0	2.3	3.3	1.9	10	0
04	3.3	4.7	2.6	0.1	2.7	8	0
06	6.2	4.9	2.9	0.1	3.5	7	0
08	0.5	5.1	4.2	0.1	2.5	7	0
10	0.1	2.9	1.4	0.7	1.3	7	0
12	1.1	0.8	2.9	3.3	2.0	7	0
14	2.5	6.4	4.8	2.2	3.9	6	0
16	4.7	3.2	1.1	2.3	2.8	6	0
18	6.2	1.6	2.5	4.8	3.8	6	0
20	4.1	1.6	0.6	1.2	1.9	6	0
22	5.3	5.7	0.8	6.6	4.6	7	0
24	3.0	6.1	0.1	5.7	3.7	7	0
26	2.6	3.1	7.1	6.5	4.8	7	0
28	0.8	0.7	0.1	4.6	1.6	8	0
30	2.8	4.6	5.3	4.1	4.2	8	0
32	0.7	4.9	8.1	1.6	3.8	8	0
34	0.6	3.4	5.4	2.6	3.0	9	0
36	0.6	3.5	1.8	1.4	1.8	10	0
38	0.1	4.0	1.2	1.9	1.8	11	0
40	0.4	4.3	1.3	1.1	1.8	11	0
42	0.3	0.8	0.5	0.2	0.5	20	3
44	0.1	0.7	0.6	1.4	0.7	24	3
46	0.1	0.3	0.6	1.6	0.6	26	3
48	0.1	3.9	6.2	1.3	2.9	20	3
50	6.3	0.7	6.6	54.6	17.0	24	4
52	7.6	0.9	45.8	0.3	13.7	30	4
54	6.4	22.8	83.3	82.8	48.8	30	4
56	108.7	71.3	86.9	55.9	80.7	27	4
58	4.0	32.2	65.1	87.9	47.3	26	4
TOTAL	180.5	205.8	351.9	340.2	269.6		

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 17 at 150 min
Preheater Deposit Code: >4
TDR Spun Deposit Rating: 30 at 52

Jet A-1 With Tetralin (5%) AL-13633-T at 268°C (515°F)
With Stainless Steel Heater Tube - Test 2*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	Mark 9 TDR	Visual Rating
02	5.3	0.4	0.8	0.2	1.7	13	0
04	1.4	1.2	4.1	0.3	1.7	12	0
06	3.7	5.3	4.7	0.1	3.4	10	0
08	6.3	3.5	1.9	0.2	3.0	9	0
10	4.4	0.6	4.2	0.1	2.3	9	0
12	4.4	0.8	4.0	0.1	2.3	9	0
14	0.7	6.3	1.2	0.1	2.0	9	0
16	1.3	0.1	2.4	0.4	1.1	8	0
18	8.7	6.3	4.4	5.5	6.2	8	0
20	2.0	5.5	4.9	5.2	4.4	8	0
22	6.2	5.9	2.2	5.0	4.8	8	0
24	5.6	6.3	3.0	5.4	5.1	9	0
26	3.8	3.8	0.5	6.1	3.6	9	0
28	0.9	0.7	0.4	1.9	1.0	10	0
30	3.8	5.9	0.1	1.1	2.7	11	0
32	4.5	6.0	0.4	0.5	2.8	11	0
34	4.7	4.2	1.5	5.3	3.9	11	0
36	0.9	4.4	1.3	0.9	1.9	12	0
38	5.8	6.0	6.6	5.9	6.1	12	0
40	6.7	3.4	7.5	1.0	4.6	18	0
42	5.0	2.5	4.8	3.2	3.9	24	2
44	3.0	4.9	5.6	6.1	4.9	26	3
46	5.6	3.3	4.4	5.1	4.6	22	3
48	7.3	3.4	0.9	6.5	4.5	26	3
50	18.0	0.1	3.3	14.8	9.0	29	3
52	52.7	71.9	1.6	59.5	46.4	32	4
54	168.7	106.7	1.7	90.5	91.9	34	4
56	224.0	208.0	108.5	73.2	153.4	31	4
58	172.8	127.5	19.8	147.2	116.8	30	4
TOTAL	738.2	604.5	201.9	451.5	500.0		

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 139 min
Preheater Deposit Code: >4
TDR Spun Deposit Rating: 29 at 50

Jet A-1 With Tetralin (5%) AL-13633-T at 268°C (515°F)
With Stainless Steel Heater Tube - Test 3*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	Mark 9 TDR	Visual Rating
02	0.2	0.2	3.7	0.3	0.3	18	1
04	4.5	0.8	0.4	0.6	0.6	13	0
06	1.6	1.8	0.9	6.8	2.8	11	0
08	4.1	0.1	4.2	0.7	2.3	10	0
10	5.9	0.6	0.9	5.1	3.1	10	0
12	5.3	0.5	0.6	4.9	2.8	10	0
14	5.4	0.1	3.4	6.0	3.7	10	0
16	4.3	0.1	2.4	3.9	2.7	11	0
18	4.2	0.1	3.9	0.2	2.1	10	0
20	5.2	2.5	4.3	0.2	3.0	10	0
22	2.7	0.1	3.5	5.4	2.9	10	0
24	5.6	5.2	0.5	6.0	4.3	10	0
26	1.8	0.1	4.5	6.1	3.2	11	0
28	2.2	0.5	4.9	4.2	3.0	11	0
30	2.3	0.9	3.2	4.2	2.6	12	0
32	4.1	6.3	0.1	4.0	3.6	12	0
34	0.4	5.7	0.2	2.5	2.2	13	0
36	0.5	0.2	0.1	4.0	1.2	15	0
38	0.1	5.0	3.4	2.9	2.8	17	0
40	4.1	1.0	2.9	1.6	2.4	17	0
42	0.3	6.6	5.4	2.6	3.7	25	2
44	6.1	7.3	1.0	4.5	4.7	26	2
46	1.2	0.5	0.7	0.3	0.7	24	2
48	5.5	6.6	4.9	0.8	4.5	27	3
50	3.2	4.0	0.6	0.5	2.1	30	3
52	20.1	79.5	55.5	6.2	40.3	32	4
54	142.1	57.9	138.7	23.8	90.6	32	4
56	183.6	169.7	44.5	197.0	148.7	30	4
58	142.1	134.5	68.5	25.8	92.7	27	3
TOTAL	568.7	498.6	368.0	331.1	441.4		

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 127 min
Preheater Deposit Code: >4
TDR Spun Deposit Rating: 30 at 50

Jet A-1 With Thiophene and Tetralin AL-13636-T at 281°C (538°F)
With Stainless Steel Heater Tube - Test 1*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	Mark 9 TDR	Visual Rating
02	1.4	1.4	0.5	0.8	1.0	17	2
04	3.6	0.4	1.5	0.6	1.5	16	2
06	2.7	0.4	1.9	1.5	1.6	14	2
08	3.6	0.6	4.8	2.7	2.9	13	2
10	5.0	0.4	1.1	2.4	2.2	13	2
12	1.7	0.5	1.8	0.5	1.1	13	2
14	3.6	0.1	5.1	0.3	2.3	14	2
16	5.1	0.3	4.5	0.4	2.6	15	2
18	4.5	1.0	6.9	0.3	3.1	15	2
20	5.5	3.2	4.3	0.1	3.3	16	2
22	6.1	0.4	4.4	0.1	2.7	18	2
24	5.0	0.8	4.1	0.1	2.5	19	2
26	2.1	0.6	5.3	4.7	3.2	27	2
28	5.9	0.3	4.8	2.8	3.4	26	3
30	5.7	0.9	0.9	1.8	2.3	20	3
32	7.8	1.1	4.5	3.1	4.1	21	3
34	23.0	1.1	13.5	2.3	10.0	25	3
36	74.7	3.7	85.7	1.7	41.5	28	3
38	71.5	6.8	125.7	2.2	52.3	31	>3
40	178.3	8.9	150.7	2.0	85.0	35	>3
42	267.0	170.6	278.0	93.3	202.2	40	4
44	378.0	310.0	374.0	245.0	326.8	42	>4
46	443.0	434.0	448.0	382.0	426.8	49	>4
48	559.0	524.0	540.0	412.0	508.8	50	>4
50	539.0	616.0	581.0	560.0	574.0	50	>4
52	630.0	687.0	651.0	621.0	647.3	50	>4
54	673.0	945.0	785.0	662.0	766.3	50	>4
56	755.0	947.0	731.0	737.0	792.5	50	>4
58	708.0	867.0	816.0	944.0	833.8	50	>4
TOTAL	5369.0	5533.0	5636.0	4687.0	5307.0		

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 94 min
Preheater Deposit Code: >4
TDR Spun Deposit Rating: 50 at 48

Jet A-1 With Thiophene and Tetralin AL-13636-T at 281°C (538°F)
With Stainless Steel Heater Tube - Test 2*

Tube Station	Dielectric Strength, Volts					Mark 9 TDR	Visual Rating
	0°	90°	180°	270°	Dielectric Average		
02	1.5	1.6	0.5	1.8	1.4	19	2
04	4.6	1.6	3.9	1.1	2.8	18	2
06	1.4	4.8	1.4	5.8	3.3	18	2
08	2.5	0.2	4.2	6.3	3.3	17	2
10	2.0	5.0	1.5	4.5	3.3	17	2
12	9.3	4.8	3.1	2.4	4.9	17	2
14	1.1	4.5	5.3	3.6	3.6	16	2
16	4.8	7.3	6.7	4.0	5.7	16	2
18	4.1	3.8	6.2	5.4	4.9	17	2
20	7.8	5.4	7.2	4.5	6.2	17	2
22	5.6	7.7	5.9	1.5	5.2	18	2
24	1.7	3.9	6.5	6.2	4.6	19	2
26	3.8	3.3	6.9	6.3	5.1	23	3P
28	4.1	6.2	4.5	5.0	4.9	27	3P
30	4.1	7.1	4.7	7.1	5.7	27	3P
32	0.6	1.0	9.1	1.5	3.0	23	3P
34	6.5	11.2	48.3	8.1	18.5	23	4P
36	26.6	32.9	40.3	2.8	25.6	30	4P
38	21.3	18.1	84.3	116.1	59.9	33	4
40	142.2	179.2	139.0	115.3	143.9	38	4
42	287.0	238.0	174.3	266.0	241.3	43	>4
44	282.0	285.0	302.0	349.0	304.[illegible]	46	>4
46	356.0	351.0	406.0	466.0	394.8	50	>4
48	426.0	472.0	497.0	641.0	509.0	50	>4
50	775.0	673.0	586.0	793.0	706.8	50	>4
52	822.0	824.0	863.0	829.0	834.5	50	>4
54	900.0	900.0	915.0	887.0	900.5	50	>4
56	920.0	886.0	936.0	921.0	915.8	50	>4
58	847.0	853.0	867.0	885.0	863.0	50	>4
TOTAL	5871.0	5792.0	5936.0	6346.0	5986.0		

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 84 min
Preheater Deposit Code: >4
TDR Spun Deposit Rating: 50 at 46

Jet A-1 With Thiophene and Tetralin AL-136[illegible]6-T at 281°C (538°F)
With Stainless Steel Heater Tube - Test 3*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	Mark 9 TDR	Visual Rating
02	2.3	3.1	0.2	0.5	1.5	13	1
04	3.9	6.5	0.7	0.2	2.8	11	1
06	2.3	4.5	1.4	0.3	2.1	9	1
08	4.1	4.9	0.7	0.5	2.5	9	1
10	2.0	6.9	0.1	4.0	3.2	9	1
12	2.1	4.1	0.8	0.5	1.9	9	1
14	6.1	4.7	0.1	0.7	2.9	9	1
16	4.4	3.9	3.8	0.1	3.0	10	1
18	4.5	2.6	1.3	0.4	2.9	10	1
20	4.7	3.1	1.2	0.1	2.3	1[illegible]	1
22	4.1	3.3	4.0	0.3	2.9	13	1
24	4.1	4.4	4.8	0.3	3.4	15	1
26	0.3	2.2	0.2	0.1	0.7	23	3
28	4.1	5.8	4.3	0.1	3.6	26	[illegible]
30	4.1	5.8	2.9	0.4	3.3	21	
32	3.9	11.5	4.3	0.5	5.0	17	3P
34	4.7	2.9	17.3	5.0	7.5	13	3P
36	3.8	4.9	42.6	6.2	14.4	26	3P
38	38.6	35.7	68.7	38.1	45.3	29	4
40	89.4	48.5	81.2	139.3	89.6	34	4
42	108.7	71.0	151.0	204.0	133.7	39	4
44	159.2	191.0	258.0	256.0	216.1	42	>4
46	285.0	241.0	328.0	330.0	296.0	50	>4
48	407.0	325.0	412.0	362.0	376.5	50	>4
50	473.0	414.0	515.0	489.0	472.8	50	>4
52	618.0	435.0	621.0	519.0	548.3	50	>4
54	687.0	673.0	637.0	614.0	652.8	50	>4
56	765.0	647.0	719.0	607.0	684.5	50	>4
58	217.0	531.0	483.0	628.0	464.8	50	>4
TOTAL	3506.0	3697.0	4364.0	4207.0	4046.0		

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 90 min
Preheater Deposit Code: >4
TDR Spun Deposit Rating: 50 at 46

APPENDIX F

JFTOT DATA COMPARING ADDITIVE EFFECTS AND FLOW RATES

Cat 1-H AL-13618-F at 260°C (500°F), Flow Rate of
4.5 mL/minute for 100 Minutes - Test 1051T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	Mark 9 TDR	Visual Rating
02	4.2	1.6	3.4	4.2	3.4	4	1
04	6.9	4.0	2.1	4.8	4.5	3	1
06	3.6	2.9	4.6	1.7	3.2	1	1
08	3.9	3.2	4.9	3.5	3.9	1	1
10	4.1	2.3	4.4	2.3	3.3	1	1
12	3.7	1.1	5.4	5.5	3.9	1	1
14	3.2	3.1	3.8	3.3	3.4	1	1
16	3.7	2.8	3.0	5.7	3.8	1	1
18	3.7	2.5	3.3	4.6	3.5	2	1
20	4.1	1.8	3.1	7.3	4.1	3	1
22	3.4	2.8	3.5	5.9	3.9	4	1
24	3.2	2.4	3.1	7.5	4.1	5	1
26	3.2	4.0	2.1	3.7	3.3	7	1
28	3.0	4.1	2.8	4.0	3.5	8	1
30	3.4	4.2	6.8	6.2	5.2	11	1
32	2.1	4.8	3.5	9.9	5.1	13	2
34	3.0	6.5	4.4	5.5	4.9	15	2
36	4.4	7.1	5.9	4.9	5.6	18	3
38	4.0	3.3	2.2	18.8	7.1	19	3
40	4.7	16.1	4.4	4.5	7.4	19	3
42	4.0	19.6	8.3	22.4	13.6	18	3
44	4.5	16.2	18.3	12.5	12.9	17	3
46	4.1	22.7	17.7	7.1	12.9	15	3
48	3.4	6.1	12.2	4.6	6.6	13	2
50	3.2	3.9	5.1	16.1	7.1	9	2
52	4.2	5.3	5.9	7.7	5.8	8	1
54	4.0	5.6	4.2	5.4	4.8	7	1
56	3.4	4.1	8.0	5.1	5.2	7	1
58	2.9	6.3	6.4	0.8	4.1	8	1
TOTAL	109.2	170.4	162.8	195.5	160.1	239	
VOLUME, $cm^3 \times 10^{-7}$	62	97	93	111	91		

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 0
Preheater Deposit Code: 3
TDR Spun Deposit Rating: 19 at 38

Cat 1-H AL-13618-F With FOA-15* at 260°C (500°F), Flow Rate 4.5 mL/minute For 100 Minutes - Test 1056T**

Tube Station	Dielectric Strength, Volts					Mark 9 TDR	Visual Rating
	0°	90°	180°	270°	Dielectric Average		
02	3.4	3.4	4.5	4.7	4.0	5	1
04	1.5	3.0	3.4	5.0	3.2	4	1
06	3.2	3.9	3.8	3.9	3.7	2	1
08	0.2	3.5	3.4	3.5	2.7	2	1
10	2.3	3.7	2.8	5.3	3.5	1	1
12	6.4	1.5	5.3	6.1	4.8	1	1
14	5.7	1.8	4.2	4.1	4.0	1	1
16	2.8	3.8	4.9	4.6	4.0	2	1
18	2.1	0.9	6.6	5.4	3.8	2	1
20	4.6	4.2	4.8	4.3	4.5	3	1
22	0.9	2.9	5.2	2.9	3.0	4	1
24	3.9	4.2	1.7	4.9	3.7	4	1
26	4.3	3.5	3.8	5.5	4.3	7	1
28	7.0	4.2	3.7	4.0	4.7	10	1
30	1.8	4.4	4.5	3.9	3.7	15	1
32	1.9	8.7	5.9	4.8	5.3	18	3
34	11.2	11.6	7.2	10.8	10.2	19	3
36	7.8	10.2	12.8	15.5	11.6	21	3
38	7.1	11.3	12.7	10.1	10.3	21	3
40	9.5	3.8	11.4	9.2	8.5	21	3
42	4.4	26.3	16.9	6.6	13.6	21	3
44	5.5	26.2	11.6	3.4	11.7	20	3
46	2.1	1.3	4.4	6.1	3.5	17	2
48	4.8	5.8	6.8	9.7	6.8	14	2
50	3.1	8.4	5.7	1.8	4.8	10	1
52	4.5	3.7	4.1	9.5	5.5	9	1
54	3.5	5.8	4.3	6.5	5.2	11	1
56	5.1	2.3	4.2	3.0	3.8	19	1
58	9.7	4.8	13.7	8.0	9.1	19	>4
TOTAL	130.3	179.1	185.3	173.1	167.5	303	
VOLUME, $cm^3 \times 10^{-7}$	74	102	106	99	95		

*25 lbs/1000 bbl FOA-15

**JFTOT, D 3241

Change in Pressure Drop, mm of Hg: 0

Preheater Deposit Code: >3

TDR Spun Deposit Rating: 21 at 36

Cat 1-H AL-13618-F at 260°C (500°F), Flow Rate of
3.0 mL/minute for 150 Minutes - Test 1052T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	Mark 9 TDR	Visual Rating
02	2.6	3.9	4.6	0.6	2.9	5	1
04	2.7	4.3	3.5	1.3	3.0	4	1
06	3.8	3.1	1.5	0.2	2.2	6	1
08	3.4	1.7	1.7	0.7	1.9	8	1
10	0.1	0.6	3.6	0.6	1.2	11	1
12	2.6	3.1	1.2	0.2	1.8	15	1
14	3.4	1.1	3.2	0.9	2.2	18	3
16	2.3	1.5	4.0	2.0	2.5	19	3
18	3.2	1.5	3.5	1.9	2.5	14	4
20	1.4	4.9	7.6	2.1	4.0	8	>4
22	8.5	5.1	4.6	2.7	4.0	8	4P
24	15.8	14.2	48.4	4.3	20.7	19	4P
26	29.1	66.8	75.7	16.4	47.0	20	4P
28	47.6	93.8	75.7	54.1	67.8	23	4P
30	80.7	117.0	104.0	63.9	91.4	31	4P
32	106.0	182.0	176.0	106.0	143.0	36	4P
34	191.0	276.0	258.0	262.0	247.0	41	>4
36	420.0	624.0	453.0	488.0	496.0	54	>4
38	668.0	908.0	836.0	945.0	839.0	56	>4
40	810.0	948.0	920.0	948.0	907.0	56	>4
42	905.0	948.0	949.0	949.0	938.0	56	>4
44	437.0	889.0	459.0	946.0	683.0	56	>4
46	741.0	787.0	845.0	777.0	788.0	54	>4
48	607.0	632.0	625.0	658.0	631.0	52	>4
50	292.0	339.0	9.5	387.0	257.0	41	4
52	119.0	115.0	3.6	171.0	102.0	27	4
54	20.7	56.4	3.2	74.8	38.8	21	2
56	2.2	31.7	2.4	27.8	16.0	21	AW**
58	4.0	4.8	1.0	3.7	3.4	19	AW
TOTAL	5530.0	7064.0	5884.0	6895.0	6344.0	799	
VOLUME, $cm^3 \times 10^{-7}$	3152	4026	3354	3930	3616		

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 30 minutes
Preheater Deposit Code: >4
TDR Spun Deposit Rating: >50 at 38
**AW=Abnormal White Deposit

Cat 1-H AL-13618-F at 260°C (500°F) With FOA-15*,
Flow Rate of 3.0 mL/minute for 150 Minutes - Test 1057T**

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	Mark 9 TDR	Visual Rating
02	3.0	2.9	0.3	3.7	2.5	1	1
04	1.4	1.5	3.3	3.1	2.3	0	1
06	3.8	1.2	1.8	1.9	2.2	0	1
08	0.6	2.2	0.9	1.3	1.3	0	1
10	6.4	2.4	0.5	5.6	3.7	0	1
12	6.0	3.4	1.8	4.4	3.9	0	1
14	3.6	1.0	1.5	3.2	2.3	0	1
16	2.4	3.3	3.3	2.1	2.8	0	1
18	1.3	1.7	1.4	3.1	1.9	1	1
20	3.9	1.9	4.9	3.5	3.6	2	1
22	3.0	0.3	3.2	2.4	2.2	5	1
24	4.0	2.8	10.6	2.4	5.0	11	2
26	3.9	3.6	12.2	7.8	6.9	17	4
28	2.6	9.6	19.4	10.5	10.5	17	4
30	4.6	3.5	19.6	12.7	10.1	11	4
32	8.4	11.5	18.3	6.2	11.1	7	3
34	7.0	4.7	17.7	14.5	11.0	6	3
36	14.8	0.9	26.2	12.1	13.5	5	3
38	24.4	4.3	13.3	5.2	11.8	5	3
40	35.7	9.6	11.0	11.9	17.1	5	3
42	37.8	3.2	2.1	5.3	12.1	5	3
44	42.2	1.9	16.0	3.5	13.0	5	3
46	29.3	1.8	14.3	6.4	13.0	6	3
48	30.7	8.3	3.5	3.3	11.5	8	3
50	4.4	4.2	1.1	3.1	3.2	11	3
52	8.7	2.9	4.0	4.3	5.0	10	3
54	7.9	4.7	6.3	2.4	5.3	8	4
56	39.1	15.4	5.1	7.1	16.7	50	4
58	207.0	181.0	236.0	246.0	218.0	46	4
TOTAL	548.0	296.0	460.0	399.0	424.0	242	
VOLUME, $cm^3 \times 10^{-7}$	312	169	262	227	242		

*25 lbs/1000 bbl FOA-15
**JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 36 at 150 minutes
Preheater Deposit Code: 4
TDR Spun Deposit Rating: 50 at 56

Cat 1-H AL-13618-F at 260°C (500°F), Flow Rate of 1.5 mL/min for 300 Minutes - Test 1053T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	Mark 9 TDR	Visual Rating
02	2.1	3.1	2.9	1.1	2.3	8	1
04	1.1	1.3	3.7	1.0	1.8	7	1
06	3.7	0.8	3.4	2.6	2.6	15	1
08	2.7	2.9	3.4	2.7	2.9	17	3
10	8.1	1.1	6.4	1.0	4.2	13	3
12	12.4	3.6	2.0	8.6	6.7	8	3
14	17.5	2.3	3.7	39.2	15.7	8	4
16	19.4	18.1	23.4	51.1	28.0	23	4
18	47.7	85.1	98.3	72.6	75.9	21	4
20	42.8	111.0	139.0	112.0	101.0	29	4
22	113.0	195.0	211.0	171.0	173.0	41	>4
24	228.0	303.0	296.0	257.0	271.0	46	>4
26	409.0	468.0	387.0	434.0	425.0	54	>4
28	605.0	593.0	575.0	595.0	592.0	57	>4
30	949.0	949.0	945.0	903.0	937.0	58	>4
32	949.0	949.0	949.0	949.0	949.0	59	>4
34	949.0	949.0	949.0	870.0	929.0	59	>4
36	946.0	949.0	949.0	646.0	873.0	58	>4
38	708.0	664.0	710.0	331.0	603.0	57	>4
40	526.0	480.0	565.0	365.0	484.0	54	>4
42	195.0	225.0	252.0	143.0	204.0	45	4
44	89.7	102.0	168.0	13.1	93.2	34	AW**
46	37.6	90.1	87.3	5.1	55.0	22	AW
48	24.1	13.6	68.6	40.7	36.8	17	AW
50	3.9	17.3	17.7	4.8	10.9	14	AW
52	4.6	5.6	48.5	8.7	16.9	11	AW
54	3.0	0.7	16.3	6.4	6.6	10	AW
56	3.0	6.5	3.3	6.9	4.9	9	AW
58	2.7	2.1	4.2	4.7	3.4	10	AW
TOTAL	6903.0	7191.0	7488.0	6046.0	6909.0	864	
VOLUME, $cm^3 \times 10^{-7}$	3935	4099	4268	3446	3938		

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 166 minutes
Preheater Deposit Code: >4
TDR Spun Deposit Rating: >50 at 26
**AW = Abnormal White Deposit

Cat 1-H AL-13618-F With FOA-15* at 260°C (500°F),
Flow Rate 1.5 mL/minute for 300 Minutes - Test 1058T**

Tube Station	Dielectric Strength, Volts					Mark 9 TDR	Visual Rating
	0°	90°	180°	270°	Dielectric Average		
02	2.1	2.7	1.5	2.7	2.3	0	1
04	2.4	3.1	1.2	0.9	1.9	0	1
06	1.3	2.3	1.9	0.7	1.6	0	1
08	3.8	2.0	1.0	1.0	2.0	0	1
10	3.7	1.6	2.0	0.8	2.0	0	1
12	3.2	1.6	1.2	0.7	1.7	0	1
14	4.7	2.3	1.9	1.3	2.6	1	1
16	4.9	3.7	3.4	1.4	3.4	11	2
18	3.2	3.6	5.1	1.3	3.3	12	2
20	8.1	2.7	7.9	4.8	5.9	4	>4P
22	14.3	37.9	18.4	13.3	21.0	7	>4P
24	41.1	58.6	11.3	41.7	38.2	15	>4P
26	54.3	70.1	70.8	61.5	64.2	16	>4P
28	11.1	94.3	78.3	90.0	68.4	16	>4P
30	55.7	119.0	165.0	168.0	126.9	21	>4P
32	74.1	99.1	187.0	184.0	136.1	24	>4P
34	144.0	230.0	171.0	203.0	187.0	26	>4P
36	187.0	203.0	195.0	201.0	196.5	27	>4P
38	181.0	171.0	201.0	206.0	189.8	27	>4P
40	168.0	108.0	205.0	198.0	169.8	27	>4P
42	172.0	189.0	195.0	193.0	187.3	27	>4P
44	171.0	168.0	191.0	216.0	186.5	27	>4P
46	148.0	216.0	177.0	251.0	198.0	27	>4P
48	172.0	259.0	189.0	185.0	201.3	28	>4P
50	146.0	209.0	188.0	193.0	184.0	46	>4P
52	168.0	228.0	264.0	208.0	217.0	50	4
54	195.0	204.0	190.0	145.0	183.5	52	4
56	380.0	414.0	375.0	320.0	372.3	52	4
58	345.0	338.0	273.0	276.0	308.0	56	4
TOTAL	2865.0	3442.0	3372.0	3369.0	3263.0	599	
VOLUME, $cm^3 \times 10^{-7}$	1633	1962	1922	1920	1860		

*25 lbs/1000 bbl FOA-15

**JFTOT, D 3241

Change in Pressure Drop, mm of Hg: 125 at 68 minutes

Preheater Deposit Code: >4

TDR Spun Deposit Rating: >50 at 52

Cat 1-H AL-13618-F at 260°C (500°F), Flow Rate of
3.0 mL/minute for 300 Minutes - Test 1054T*

Tube Station	Dielectric Strength, Volts					Mark 9 TDR	Visual Rating
	0°	90°	180°	270°	Dielectric Average		
02	4.4	1.0	1.5	0.6	1.9	2	1
04	1.1	3.0	1.1	1.6	1.7	2	1
06	1.0	1.6	1.0	1.1	1.2	7	1
08	1.1	0.9	3.8	1.7	1.9	12	2
10	1.8	0.8	3.9	2.0	2.1	11	4P
12	1.3	0.7	3.1	2.3	1.9	6	4P
14	4.5	3.9	3.3	1.8	3.4	3	4P
16	0.7	3.7	38.7	1.2	11.1	14	4P
18	2.9	4.8	80.2	10.5	24.6	18	4P
20	62.8	39.8	82.3	64.6	62.4	21	4P
22	109.7	107.7	146.9	52.8	104.3	31	4P
24	132.4	192.1	205.0	79.5	152.3	38	4P
26	195.0	284.0	232.0	227.0	234.5	48	>4
28	307.0	381.0	390.0	317.0	348.8	50	>4
30	541.0	527.0	576.0	609.0	563.3	53	>4
32	944.0	947.0	948.0	925.0	941.0	56	>4
34	947.0	948.0	948.0	948.0	947.8	58	>4
36	948.0	948.0	948.0	948.0	948.0	59	>4
38	948.0	948.0	920.0	948.0	941.0	59	>4
40	947.0	948.0	947.0	948.0	947.5	59	>4
42	948.0	948.0	947.0	948.0	947.8	59	>4
44	948.0	948.0	948.0	948.0	948.0	59	>4
46	948.0	948.0	948.0	948.0	948.0	58	>4
48	947.0	947.0	573.0	936.0	850.8	57	>4
50	940.0	904.0	776.0	872.0	873.0	56	>4
52	658.0	749.0	853.0	653.0	728.3	51	4
54	344.0	317.0	371.0	245.0	319.3	39	4
56	82.3	72.3	2.8	93.3	62.7	22	4
58	0.5	0.9	1.6	6.3	2.3	18	4
TOTAL	11917.0	12125.0	11900.0	11739.0	11920.0	1026	
VOLUME, $cm^3 \times 10^{-7}$	6793	6911	6783	6691	6794		

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg. 125 at 25 minutes
Preheater Deposit Code: >4
TDR Spun Deposit Rating: >50 at 30

Cat 1-H AL-13618-F With FOA-15* at 260°C (500°F),
Flow Rate of 3.0 mL/minute for 300 Minutes - Test 1061T**

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	Mark 9 TDR	Visual Rating
02	1.1	0.2	1.4	1.1	1.0	0	1
04	1.0	0.7	0.2	2.2	1.0	0	1
06	0.9	0.2	1.3	1.2	0.9	0	1
08	1.5	0.1	1.2	1.1	1.0	0	1
10	0.3	1.3	1.8	0.7	1.0	0	1
12	1.1	1.9	1.9	1.4	1.6	0	1
14	0.4	0.8	2.9	2.1	1.6	0	1
16	2.4	2.8	0.5	4.1	2.5	1	1
18	1.3	1.6	1.6	1.1	1.4	6	1
20	0.1	5.8	1.1	2.4	2.4	13	2
22	0.5	4.7	0.9	3.2	2.3	8	3P
24	3.6	1.9	2.0	8.3	4.0	4	3P
26	4.5	4.2	0.8	15.2	6.2	10	3P
28	8.8	37.2	3.9	27.9	19.5	18	3P
30	9.6	39.5	6.6	49.9	26.4	17	3P
32	68.8	58.2	45.1	69.7	60.5	18	3P
34	75.4	63.2	45.1	77.9	65.4	20	>4
36	144.0	143.8	53.6	135.7	119.3	25	>4
38	175.2	178.7	43.1	130.4	131.9	26	>4
40	137.4	127.8	6.8	123.9	99.0	26	>4
42	177.4	145.6	70.2	134.2	131.9	26	>4
44	122.9	30.5	46.4	125.1	81.2	25	>4
46	102.9	1.5	74.9	97.9	69.3	21	AG***
48	104.7	11.7	43.9	108.1	67.1	19	AG
50	20.3	12.2	89.1	84.9	51.6	18	AG
52	18.7	7.4	40.1	46.6	28.2	19	AG
54	78.2	5.9	75.3	60.2	54.9	33	4
56	131.0	171.9	167.8	128.5	149.8	54	4
58	342.0	377.0	319.0	133.4	292.9	56	>4
TOTAL	1736.0	1438.0	1149.0	1578.0	1476.0	463	
VOLUME, $cm^3 \times 10^{-7}$	990	820	655	899	841		

* 25 lbs/1000 bbl FOA-15

**JFTOT, D 3241

Change in Pressure Drop, mm of Hg: 125 at 140 minutes

Preheater Deposit Code: >4

TDR Spun Deposit Rating: 33 at 54

***AG = Abnormal Green Deposit

Cat 1-H AL-13618-F at 260°C (500°F), Flow Rate of 1.5 mL/minute for 600 Minutes – Test 1055T*

Tube Station	Dielectric Strength, Volts					Mark 9 TDR	Visual Rating
	0°	90°	180°	270°	Dielectric Average		
02	1.3	2.1	1.2	0.6	1.2	8	AW**
04	1.2	0.9	1.4	0.9	1.1	6	AW
06	1.4	1.0	0.7	1.7	1.2	5	AW
08	3.1	1.6	3.1	0.7	2.1	6	AW
10	1.1	1.5	2.6	2.9	2.0	9	AW
12	1.8	1.0	0.1	2.7	1.4	11	AW
14	2.7	1.3	2.4	3.1	2.4	12	AW
16	0.9	1.7	1.1	1.5	1.3	16	AW
18	1.0	1.5	2.7	3.3	2.1	18	AW
20	2.9	17.1	0.9	1.1	5.5	21	AW
22	17.4	36.4	1.3	2.3	14.4	24	AW
24	3.4	71.8	1.1	49.9	31.6	29	AW
26	50.4	106.7	0.9	44.7	50.7	36	3
28	106.5	164.0	4.9	62.3	84.4	43	3
30	189.3	364.0	85.3	116.7	188.8	54	4
32	407.0	536.0	428.0	605.0	494.0	56	4
34	654.0	724.0	673.0	613.0	666.0	57	4
36	948.0	948.0	757.0	948.0	900.3	58	4
38	948.0	948.7	948.0	948.0	948.0	58	>4
40	948.0	948.0	948.0	948.0	948.0	59	>4
42	948.0	948.0	948.0	948.0	948.0	59	>4
44	948.0	948.0	948.0	948.0	948.0	59	>4
46	945.0	920.0	947.0	879.0	922.8	58	>4
48	552.0	653.0	678.0	635.0	629.5	53	AP***
50	383.0	434.0	393.0	449.0	414.8	40	4P
52	263.0	290.0	276.0	237.0	266.5	30	4P
54	193.0	182.7	222.0	217.0	203.7	25	4P
56	130.7	169.8	152.7	169.4	155.7	19	4P
58	118.6	115.8	137.6	64.2	109.1	17	3
TOTAL	8771.0	9538.0	8566.0	8903.0	8945.0	946	
VOLUME, $cm^3 \times 10^{-7}$	4999	5437	4883	5075	5099		

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 210 minutes
Preheater Deposit Code: >4
TDR Spun Deposit Rating: >50 at 30

**AW = Abnormal White Deposit

***AP = Abnormal Purple Deposit

Cat 1-H AL-13618-F With FOA-15* at 260°C (500°F), Flow Rate of 1.5 mL/minute for 600 Minutes - Test 1064T**

Tube Station	Dielectric Strength, Volts					Mark 9 TDR	Visual Rating
	0°	90°	180°	270°	Dielectric Average		
02	0.7	0.9	1.0	0.8	0.9	1	1
04	1.1	0.8	0.2	1.2	0.8	0	1
06	1.7	0.9	0.9	0.9	1.1	0	1
08	2.6	0.9	0.6	0.4	1.1	0	1
10	1.4	0.8	0.8	0.9	1.0	0	1
12	1.0	0.8	1.2	0.8	1.0	4	1
14	2.7	1.5	1.1	0.9	1.6	11	4P
16	0.8	3.7	1.3	0.7	1.6	6	4P
18	9.3	15.6	1.9	3.6	7.6	10	4P
20	54.7	53.9	20.7	88.1	54.4	17	4P
22	69.9	71.3	42.8	102.6	71.7	22	4P
24	117.0	121.4	78.5	132.0	112.2	25	>4
26	172.7	130.9	113.0	171.0	146.9	31	>4
28	186.8	181.8	132.5	198.0	174.8	35	>4
30	254.0	222.0	176.3	229.0	220.3	41	>4
32	273.0	241.0	239.0	257.0	252.5	44	>4
34	310.0	252.0	274.0	280.0	279.0	46	>4
36	322.0	281.0	282.0	295.0	295.0	47	>4
38	338.0	303.0	256.0	319.0	304.0	48	>4
40	316.0	309.0	345.0	321.0	322.8	48	>4
42	291.0	301.0	316.0	306.0	303.5	48	>4
44	313.0	299.0	294.0	307.0	303.3	48	>4
46	320.0	286.0	244.0	290.0	285.0	47	>4
48	299.0	271.0	256.0	281.0	276.8	47	>4
50	258.0	261.0	280.0	272.0	267.8	50	>4
52	282.0	321.0	197.0	201.0	250.3	58	>4
54	402.0	390.0	264.0	572.0	407.0	58	>4
56	665.0	231.0	386.0	698.0	495.0	58	4
58	331.0	307.0	247.0	469.0	338.5	58	4
TOTAL	5596.0	4860.0	4453.0	5799.0	5178.0	908	
VOLUME, $cm^3 \times 10^{-7}$	3190	2770	2538	3305	2951		

*25 lbs/1000 bbl FOA-15

**JFTOT, D 3241

Change in Pressure Drop, mm of Hg: 125 at 90 minutes

Preheater Deposit Code: >4

TDR Spun Deposit Rating: >50 at 52

1% Sulfur Referee Diesel AL-13619-F at 204°C (400°F) - Test 1078T*

Tube Station	Dielectric Strength, Volts					Mark 9 TDR	Visual Rating
	0°	90°	180°	270°	Dielectric Average		
02	0.8	1.4	0.7	1.1	1.0	0	0
04	0.1	0.9	1.2	0.9	0.8	0	0
06	0.3	0.1	0.6	0.6	0.4	0	0
08	0.9	0.9	0.5	0.5	0.7	0	0
10	0.8	0.1	0.8	2.0	0.5	0	0
12	1.3	0.2	0.6	1.6	0.9	0	0
14	1.2	0.3	2.0	1.1	1.2	0	0
16	0.9	1.3	0.9	2.9	1.5	0	0
18	0.9	1.0	2.2	0.9	1.3	0	0
20	0.1	1.1	1.0	1.0	0.8	0	0
22	1.1	3.1	2.6	1.3	2.0	1	0
24	1.8	0.9	1.7	0.8	1.3	1	0
26	1.7	1.0	3.3	2.4	2.1	3	0
28	1.1	0.8	1.2	0.9	1.0	4	2
30	2.8	1.0	3.3	1.1	2.1	6	3
32	2.0	2.4	2.0	2.4	2.2	7	3
34	1.5	3.4	1.0	2.2	2.0	8	>4
36	1.3	1.4	3.7	2.8	2.3	10	>4
38	1.9	1.1	1.5	1.0	1.4	10	>4
40	0.9	0.8	5.3	0.8	2.0	10	>4
42	0.9	3.2	3.6	2.0	2.4	10	>4
44	2.0	2.8	3.8	0.8	2.4	10	3
46	0.7	2.6	1.6	2.1	1.8	8	3
48	1.3	2.7	2.6	1.4	2.0	6	2
50	0.9	1.1	2.2	1.2	1.4	4	0
52	1.0	1.8	1.0	1.6	1.4	2	0
54	1.1	0.9	1.1	2.7	1.5	1	0
56	1.0	3.5	2.2	1.0	1.9	1	0
58	1.7	1.1	1.3	1.3	1.4	2	0
TOTAL	34.0	42.9	55.5	42.4	43.7		

*JFTOT, D 3241

Change in Pressure Drop, mm of Hg: 125 at 90 minutes

Preheater Deposit Code: >2

TDR Spun Deposit Rating: 10 at 36

1% Sulfur Referee Diesel AL-13619-F at 204°C (400°F) With Stainless Steel Heater Tube - Test 1083T*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	Mark 9 TDR	Visual Rating
02	2.6	1.5	0.2	2.9	1.8	16	0
04	1.0	0.6	1.1	0.8	0.9	13	0
06	4.5	1.0	4.0	0.8	2.6	11	0
08	3.5	1.1	5.7	2.6	3.2	9	0
10	2.1	0.1	2.3	0.2	1.2	9	0
12	1.0	0.2	1.5	2.1	1.2	10	0
14	0.9	0.4	0.8	3.1	1.3	10	0
16	0.9	0.4	4.7	1.2	1.8	11	1
18	3.5	0.3	2.8	1.3	2.0	10	1
20	0.7	0.3	0.1	1.9	0.8	10	1
22	0.7	0.1	2.6	4.2	1.9	11	1
24	1.1	2.2	1.6	1.7	1.7	12	AB**
26	1.1	0.1	1.1	1.5	1.0	10	AW***
28	1.0	0.1	0.5	2.4	1.0	10	AW
30	1.2	0.1	2.7	2.5	1.6	14	>4
32	1.7	3.7	1.0	2.3	2.2	26	>4
34	1.7	2.9	5.0	1.9	2.9	18	>4
36	3.0	3.1	6.3	2.0	3.6	13	>4
38	3.2	2.9	2.7	3.9	3.2	22	>4
40	0.5	1.2	6.7	2.6	2.8	23	>4
42	6.0	2.5	3.4	4.3	4.1	29	>4
44	4.2	0.7	5.7	4.0	3.7	30	>4
46	8.0	2.7	6.6	4.2	5.4	40	>4
48	3.7	1.5	13.5	8.7	6.9	44	>4
50	3.9	2.9	21.2	15.7	10.9	44	>4
52	7.7	2.3	23.7	3.6	9.3	49	>4
54	4.8	7.5	2.7	3.5	4.6	50	>4
56	4.6	19.6	9.5	5.7	9.9	48	>4
58	1.0	2.3	0.2	0.1	0.9	46	>4
TOTAL	79.8	64.3	139.9	89.4	94.4		

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 75 minutes
Preheater Deposit Code: 4P
TDR Spun Deposit Rating: 50 at 54
** AB = Abnormal Blue Deposit
***AW = Abnormal White Deposit

Jet A-1 AL-13623-T at 281°C (538°F) - Test 1079G*

Tube Station	Dielectric Strength, Volts					Mark 9 TDR	Visual Rating
	0°	90°	180°	270°	Dielectric Average		
02	2.2	1.5	1.1	2.0	1.7	0	0
04	2.2	2.7	2.8	2.3	2.5	0	0
06	0.7	3.5	2.7	2.6	2.4	0	0
08	1.2	3.7	3.0	2.9	2.7	0	0
10	1.4	3.3	1.7	3.9	2.6	0	0
12	3.7	2.4	3.5	3.2	3.2	0	0
14	0.9	3.2	0.9	3.5	2.1	0	0
16	1.3	2.1	2.3	2.5	2.1	0	0
18	1.4	1.1	2.4	1.1	1.5	0	0
20	0.9	2.5	2.2	2.2	2.0	0	0
22	1.0	2.8	0.9	2.6	1.8	0	0
24	1.0	1.8	1.4	1.9	1.5	0	AW**
26	1.5	2.5	1.7	2.1	2.0	0	AW
28	1.0	1.7	1.2	1.3	1.3	0	AW
30	1.9	2.8	0.7	0.6	1.5	3	AW
32	2.6	3.1	1.4	2.5	2.4	5	AW
34	0.9	3.5	1.0	2.7	2.0	7	4
36	1.0	3.0	3.3	1.2	2.1	6	4
38	2.6	3.4	3.3	3.9	3.3	4	>4
40	5.1	2.4	2.2	6.3	4.3	2	>4
42	16.9	2.8	18.9	1.2	10.0	2	>4
44	6.6	10.3	3.6	3.9	6.1	1	>4
46	6.1	4.5	20.0	3.9	8.6	2	>4
48	3.6	4.7	21.0	10.6	10.0	3	>4
50	2.9	4.8	6.5	9.8	6.0	6	>4
52	3.7	3.8	2.7	1.1	2.8	4	>4
54	2.7	1.2	3.1	3.7	2.7	2	AW
56	1.2	2.7	3.2	0.9	2.0	0	0
58	1.6	1.6	2.7	1.6	1.9	0	0
TOTAL	79.8	89.4	121.4	88.0	95.1		

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 120 minutes
Preheater Deposit Code: 4P
TDR Spun Deposit Rating: 7 at 34

** AW = Abnormal White Deposit

Jet A-1 AL-13623-T at 281°C (538°F) With Stainless
Steel Heater Tube - Test 1084G*

Tube Station	Dielectric Strength, Volts					Mark 9 TDR	Visual Rating
	0°	90°	180°	270°	Dielectric Average		
02	4.6	0.9	0.4	0.2	1.5	16	0
04	3.0	0.8	0.3	0.8	1.2	13	0
06	1.5	1.3	0.1	2.0	1.2	10	0
08	2.4	1.3	0.6	1.4	1.4	10	0
10	3.1	0.4	1.3	1.6	1.6	10	0
12	1.6	1.0	1.2	1.7	1.4	10	0
14	2.1	1.4	1.7	0.5	1.4	11	0
16	2.0	0.9	1.7	0.5	1.3	11	0
18	1.6	1.6	2.8	2.5	2.1	11	0
20	1.4	1.9	4.3	2.3	2.5	10	0
22	3.8	1.3	2.3	4.3	2.9	11	0
24	4.4	5.1	3.5	4.9	4.5	12	0
26	5.4	5.5	3.3	4.6	4.7	10	0
28	5.3	6.3	4.6	4.8	5.3	10	0
30	5.9	5.5	3.8	3.9	4.8	16	0
32	4.9	3.9	4.8	1.7	3.8	26	4P
34	5.2	4.8	4.3	1.1	3.9	20	4P
36	15.8	1.4	21.4	2.3	10.2	15	4P
38	64.3	5.7	48.9	0.6	29.9	24	4P
40	74.5	62.8	51.0	6.7	48.8	24	4
42	145.6	197.0	128.2	88.5	139.8	30	4
44	181.5	210.0	181.3	30.5	150.8	34	>4
46	324.0	218.0	255.0	212.0	252.3	41	>4
48	283.0	410.0	289.0	338.0	330.0	45	>4
50	391.0	467.0	432.0	368.0	414.5	48	>4
52	446.0	410.0	444.0	403.0	425.8	50	>4
54	405.0	454.0	425.0	385.0	417.3	50	>4
56	479.0	466.0	392.0	345.0	418.0	48	>4
58	291.0	316.0	300.0	72.8	245.0	45	>4
TOTAL	3159.0	3262.0	3009.0	2291.0	2928.0		

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 125 at 69 minutes
Preheater Deposit Code: >4
TDR Spun Deposit Rating: 50 at 50

Diesel Control AL-13630-F at 268°C (515°F) -
Test 108LJ*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	Mark 9 TDR	Visual Rating
02	0.6	0.5	1.0	1.6	0.9	0	0
04	1.7	0.3	0.7	0.9	0.9	0	0
06	2.0	2.1	2.0	1.4	1.9	0	0
08	0.1	0.2	0.1	0.3	0.2	0	0
10	0.4	0.3	1.8	0.9	0.9	0	0
12	1.4	1.0	3.8	1.5	1.9	0	0
14	1.8	1.5	2.8	2.7	2.2	0	0
16	1.8	3.1	4.6	3.0	3.1	0	0
18	2.8	2.9	2.9	1.2	2.5	0	0
20	1.1	1.0	1.0	0.7	1.0	0	0
22	2.7	1.5	1.9	2.0	2.0	0	1
24	3.6	1.8	5.9	5.2	4.1	0	1
26	3.7	1.9	1.1	1.1	2.0	2	2
28	3.9	4.1	1.5	3.2	3.2	4	2
30	2.6	3.3	3.7	3.9	3.4	9	2
32	4.2	6.1	4.3	3.5	4.5	13	3
34	9.0	8.0	2.9	3.3	5.8	13	4
36	4.4	17.9	3.6	4.4	7.6	10	4
38	4.8	13.2	11.4	8.1	9.4	8	>4
40	15.2	4.8	30.1	7.1	14.3	8	>4
42	28.2	12.7	7.4	4.8	13.3	8	>4
44	10.1	16.5	4.3	6.1	9.3	9	>4
46	14.8	6.4	4.5	16.7	10.6	13	>4
48	3.6	2.5	2.3	4.5	3.2	14	>4
50	6.5	7.5	1.6	4.1	4.9	10	3
52	3.1	3.2	2.2	3.6	3.0	7	3
54	3.1	3.4	1.5	3.8	3.0	6	1
56	3.6	3.4	3.0	2.7	3.2	4	1
58	4.3	1.3	1.6	3.3	2.6	7	1
TOTAL	145.1	132.4	115.5	105.6	124.9		

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 0
Preheater Deposit Code: 4P
TDR Spun Deposit Rating: 14 at 48

Diesel Control AL-13630-F at 269°C (515°F) With
Stainless Steel Heater Tube - Test 1082J*

Tube Station	Dielectric Strength, Volts 0°	90°	180°	270°	Dielectric Average	Mark 9 TDR	Visual Rating
02	2.7	1.3	2.1	2.0	2.0	14	0
04	3.2	3.3	1.6	3.1	2.8	14	0
06	1.2	2.1	2.7	1.5	1.9	13	0
08	0.7	0.5	0.3	0.1	0.4	14	0
10	2.7	1.4	0.8	0.3	1.3	14	0
12	1.2	1.1	0.6	1.3	1.1	15	0
14	0.5	0.5	1.9	0.5	0.9	15	0
16	0.6	0.5	1.7	1.4	1.1	15	0
18	2.0	1.5	1.7	1.0	1.6	14	0
20	0.6	0.7	0.4	1.1	0.7	15	0
22	2.9	2.1	3.0	2.1	2.5	16	0
24	2.3	1.7	3.8	2.6	2.6	18	0
26	0.5	1.0	4.9	1.0	1.9	20	0
28	0.5	2.1	3.0	2.4	2.0	22	0
30	1.5	1.9	2.6	2.2	2.1	23	3
32	1.6	3.6	5.1	3.0	3.3	23	3
34	3.9	5.5	7.7	1.6	4.7	23	3
36	7.2	8.4	4.6	0.9	5.3	25	4
38	3.7	7.0	6.8	0.9	4.6	28	4
40	2.2	12.9	4.6	0.7	5.1	33	4
42	2.5	15.3	5.5	0.5	6.0	27	4
44	1.1	22.5	14.6	2.1	10.1	20	4
46	5.1	46.4	31.5	0.4	20.9	31	4
48	24.7	87.2	57.9	7.9	44.4	34	4
50	141.8	104.5	122.1	42.1	102.6	41	4
52	191.0	198.0	198.0	241.0	207.0	50	>4
54	266.0	177.8	208.0	245.0	224.2	50	>4
56	318.0	297.0	306.0	276.0	299.3	50	>4
58	241.0	249.0	376.0	304.0	292.5	50	>4
TOTAL	1233.0	1257.0	1380.0	1149.0	1255.0		

*JFTOT, D 3241
Change in Pressure Drop, mm of Hg: 1 at 150 minutes
Preheater Deposit Code: >4P
TDR Spun Deposit Rating: 50 at 52

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